1942

TEXAS AGRICULTURAL EXPERIMENT STATION

A. B. CONNER, DIRECTOR,
College Station, Texas

BULLETIN NO. 614 JUNE 1942

COTTON ROOT ROT STUDIES WITH SPECIAL REFERENCE TO SCLEROTIA, COVER CROPS, ROTATIONS, TILLAGE, SEEDING RATES, SOIL FUNGICIDES, AND EFFECTS ON SEED QUALITY

C. H. ROGERS

Division of Plant Pathology and Physiology

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
T. O. WALTON, President

B13-642-6M-L180

Sclerotia, the resting bodies of the cotton root-rot fungus, have been found to a depth of 8 feet in the Blackland soils and in quantities of several million per acre in the first 3 or 4 feet of soil. The reductions in number of sclerotia following crop rotations and green manuring were scarcely large enough to explain the partial control of root rot obtained by these practices, suggesting that the beneficial effect may be on the active stage of the fungus in the soil or directly on the cotton plant.

With the usual cotton-corn-oats rotation in which the oats were followed by summer catch-crops of cowpeas and sorghum plowed under for green manure in late summer, the yield of lint cotton in 1941 was greater by 100 pounds per acre in the plots receiving this treatment than in continuous-cotton plots and the amount of root rot was 20 to 30 percent less. Similarly in 1941, the yield from cotton following plowed-under Hubam stubble (after harvesting for hay or seed) was twice as large as the yield from continuous cotton plots and root rot was reduced from 70 percent to 15 or 20 percent. Early plowing under of cotton plants in 1940 resulted in a yield increase of 120 pounds of seed cotton per acre in 1941, as compared with the usual late turning of the stalks.

Sesbania, guar, and certain selections of Brabham and Iron cowpeas are shown to be resistant to root rot and these crops may prove valuable in rotations designed for root-rot control and soil improvement.

In a 3-year study, cotton seed were planted at rates of 2, 5, and 10 seeds per hill, in hills 18 inches apart and the stand of plants was thinned to not more than 2 plants per hill in all plots at time of chopping. The plots that were planted with the fewest seeds per hill had the least root rot at the end of the season.

Subsoiling or tillage to depths of 15 inches or greater has been found to reduce the amount of root rot but no outstanding yield increase was obtained. Treatment of the soil with certain fungicides, such as crude oil, was effective when applied sufficiently deep.

Seed from plants killed early in the season by root rot were found to have lower oil and protein content and a lower viability than seed from plants that escaped root rot while the seeds were developing.

CONTENTS

COTTON ROOT ROT STUDIES WITH SPECIAL REFERENCE TO SCLEROTIA, COVER CROPS, ROTATIONS, TILLAGE, SEEDING RATES, SOIL FUNGICIDES AND EFFECTS ON SEED QUALITY[1]

C. H. Rogers, Plant Pathologist
Division of Plant Pathology and Physiology

Cotton root rot is by far the most destructive plant disease in Texas. The root rot fungus, *Phymatotrichum omnivorum* (Shear) Duggar, not only destroys cotton but attacks and rots the roots of approximately 2,000 different wild and cultivated plants, including trees, shrubs, fruit and vegetable crops, as well as various field crops. Such plants as grasses, corn, sorghum, onions, and lilies, which belong to the large class known as monocots, are practically immune to this root rot. The fungus is indigenous to the alkaline soils of the southwestern United States and northern Mexico. Root rot occurs throughout most of Texas except the High Plains area and is particularly severe in the calcareous soils of the Blackland Belt, where it has increased in severity because of continued cropping with cotton and other susceptible crops. The disease is carried over from season to season by infected roots with associated mycelial strands and by fungous resting-bodies called sclerotia.

Since the time, about fifty years ago, when the disease began to attract widespread attention, the Texas Agricultural Experiment Station and other agencies, including other State Experiment stations in the Southwest and the U. S. Department of Agriculture have been carrying on many phases of research on the cotton root rot disease, and various recommendations for control of cotton root rot have been made. Among these, emphasis has been placed on the rotation of cotton with non-susceptible crops. Just recently, some experiments indicate that the plowing under of cotton plants while green or the turning under of leguminous cover crops offers considerable control for root rot under Blackland conditions. The reader is referred to recent publications by Rea (17)[2] and Streets (25) for a digest of information concerning the disease. This bulletin presents a summary of some of the experimental work on cotton root rot, not previously reported, conducted at the Blackland Experiment Station (Substation No. 5), Temple, Texas, during the period from 1931 tc 1942.

General Methods Employed In These Studies

Field Plots: The experimental field (Fig. 1) on which most of these studies were conducted is laid out in series of one-acre plots separated by roadways (alleys) 23 feet wide and these are crossed by others 20 feet

---

[1]These investigations were greatly aided by the Work Projects Administration, Federal Works Agency, under projects operating almost continuously from 1936 through February, 1942. Cooperation of W. P. A. officials is deeply appreciated.

[2]Numbers in parentheses refer to literature cited.

wide. These alleys serve for drainage and provide access to the plots. A few of the roadways are sodded with buffalo grass *(Buchloe dactyloides)* to impede the water runoff but for the most part, they are kept free of vegetation. The acres are labeled or located by letters in one direction and by numerals in the other which serve to identify any area under study. In each of these one-acre plots there are 110 rows 132 feet long and 3 feet apart. Rows are planted about 145 feet long and when plants have attained some size, the rows are trimmed to 138 feet, leaving three feet to serve as a guard at each end. Other experimental plots are located in fields adjacent to buildings and grounds where water is available for irrigation and in the larger fields of the Soil Conservation Service Farm.

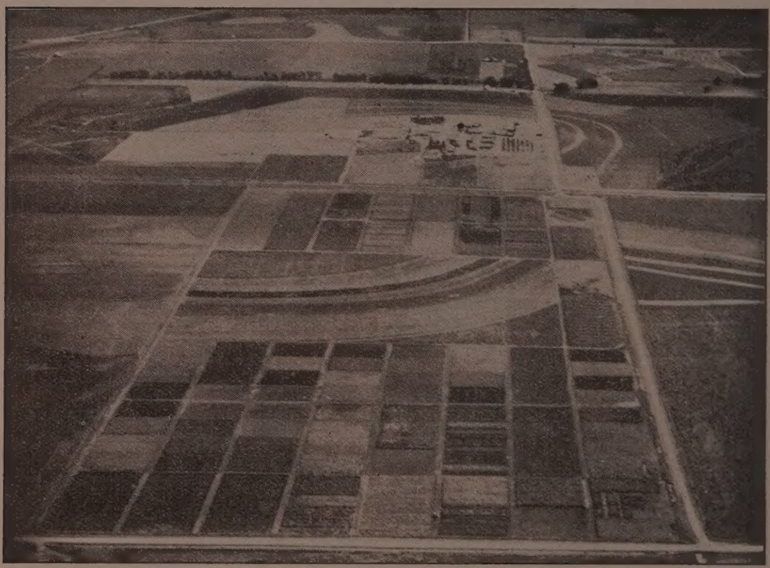

Figure 1. Aerial view of the Blackland Experiment Station looking east. The contoured area on which the rotations in Table 6 are located is in the center of the view. The large-scale rate-of-planting tests of Table 10 were located immediately to the right of the Substation buildings.

Recording of Root Rot: Records of root rot spread in the field were usually obtained at semi-monthly intervals, beginning at the time about 5 percent of the plants in each area had died from root rot. In most years, the first record was made on July 15. These data were taken by one of three methods: (1) mapping with a specially built machine, (2) measuring with a steel tape, or (3) making actual plant counts. Use

was made of a mapping machine (Fig. 2) similar to one originally designed by U. S. Department of Agriculture workers at Austin, Texas, which enabled accurate estimates of the percentage of root rot on the standard acres (132x330 ft.) or smaller plots. For larger plots, a steel tape or other ordinary methods of measuring were used. These measurements were taken and recorded in such a manner that maps showing the root-rot areas could be plotted therefrom. In some cases, as in nursery plots where shrubs or trees were tested for resistance or susceptibility, actual plant counts were made.

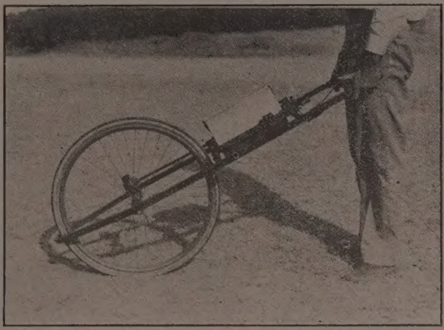

Figure 2. Machine used for mapping root rot in field plots.

Sampling for Sclerotia: Soil samples for sclerotial analysis were taken with a 6-inch post hole auger, and the sclerotia separated from the soil by methods previously described (18). An arbitrary standard of 320 auger samples were taken from each acre of land. Eight auger borings for each separate depth interval were combined to make a composite sample. A total of 40 such samples were thus taken from each area, or 10 from each quarter-acre, in cases where the acre plot was subdivided into four sections for rotation studies. Samples were taken at random over the area to be studied. The 320 auger samples per acre represent .00144 or 1/693.3 of the total soil volume per acre to any given depth interval. Briefly, the method of separating sclerotia from soil consisted of washing the soil sample, which was usually placed in barrels and pre-soaked with water for a few hours, through a power-driven machine (Fig. 3) with a coarse and a fine mesh screen. Sclerotia were separated from the gravel and shell residue remaining on the fine-mesh screen by stirring in a sugar solution of specific gravity 1.15 to 1.25. The sclerotia that were present, together with other organic matter, floated in this solution and were decanted into a fine-mesh strainer. The sclerotia were then picked by hand from the other material in a white enamelware pan, counted, and germination or viability tests obtained by incubating at 25°C. in sterile petri dishes on mo'st filter paper (Fig. 4). Germination counts were made at 5-, 15-, and 30-day intervals after plating. Sclerotia

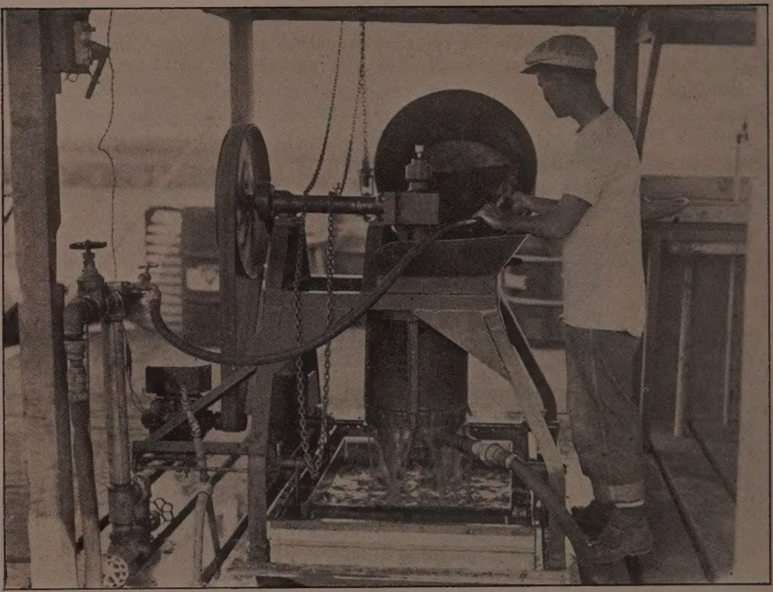

Figure 3. Apparatus used in separating sclerotia from soil.

that were highly viable usually germinated within the 5-day period. The number of sclerotia found varied from none to nearly 4000 per sample. Germination tests were made on only 100 sclerotia from the samples containing more than this number.

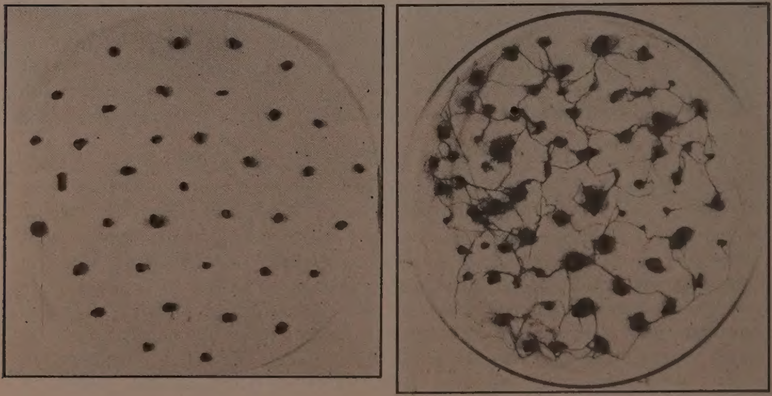

Figure 4. Sclerotia as they are separated from the soil (left). Formation of mycelial strands by germination of sclerotia (right).

Yield Records: Cotton was harvested and lint yields calculated from ginning data, in accordance with established methods of the Texas Experiment Station. Where dry forage yields are recorded, these represent air dry weights, which were obtained by drying the forage in the open for a number of days, with frequent turning of the sample to obtain as thorough and uniform drying as possible.

Inoculating Test Plants With Root Rot: In certain kinds of small plot work, especially those having to do with testing of plants for resistance to root rot, artificial inoculation (similar to methods already in use at the Substation) was resorted to quite often. The inoculum used for such purposes consisted of a section of the tap root of field-grown cotton plants about ½-inch or more in diameter at the crown, that were just beginning to wilt from root-rot infection. A section four or five inches in length was cut from the fresh root so that about ½-inch of diseased root bark was left at the infected (lower) end of each piece. Inoculations were made by inserting one or two of these pieces of infected roots in a hole made with an iron bar 1 or 2 inches from the plant to be tested and at intervals of about six feet along each row. Sometimes as many as 4 or 5 inoculations were made at succeeding intervals during the growing season; in some cases the individual plants were inoculated. After inoculation, the entire plots, or at least the areas adjacent to and including the inoculum, were irrigated. Where the inoculated plant was highly susceptible to root rot, it was usually necessary to inoculate only once. Usually, the disease spread from the inoculation centers and the advancing infections met between the points of inoculation.

Rainfall As Affecting Spread of Root Rot

It is common knowledge that rainfall in sufficient quantity to wet the soil thoroughly in July and August usually accelerates the appearance of centers of root-rot infection and hastens the spread of the disease from these centers. This, however, is not true in every case. Intermittent rains, accompanied by cloudy weather, resulting in a high relative humidity and low transpiration rate, often result in a fairly low percentage of plants killed by root rot, although soil moisture and temperature conditions in these instances may be ideal for rapid growth and spread of the fungus. A condition similar to this prevailed in the early summer of 1941. June and the first half of July of that year were unusually wet and comparatively cool. Also, the winter and spring immediately preceding those months were the wettest on record in most, if not all, of the central Texas counties. This continued wet weather in the early part of the growing season, together with a high insect infestation (mostly boll weevil) contributed towards making a vegetative type of cotton plant with a shallow root system. This condition persisted even as late as the latter part of July. At this time the weather became clear and hot with southerly winds, resulting in a rapid spread of root rot, as evidenced by sudden wilting and dying of plants. The first few inches of soil became dry within a short time and the infected shallow root systems could not

support the plants long enough to produce a fair crop of bolls. In addition to these conditions, delayed planting in some cases, caused by excessive soil moisture in the spring, together with angular leaf spot infection on leaves and bolls, and leaf and boll-worm infestations in late summer were other factors that played a part in the production of an abnormally low acre-yield of cotton in the Central Texas area in 1941.

Comparison of rainfall during the growing season of the years 1928-1941, inclusive, and root rot in three different areas planted continuously to cotton during the same period (Table 1) show that root rot spreads rapidly, with a relatively high end-season loss of plants, when there are one or more heavy rains in July or late June and early August. A high total rainfall for any given season does not necessarily mean a high root-rot loss. This loss is dependent upon the time (of season) at which the rain falls and the amount of precipitation per rain. Rains of one inch or more are sufficient to wet the soil in the upper eight inches where fungous growth is most effective in killing the plants. Infection deep in the soil may destroy the lower part of the tap root and yet not damage the plant greatly, since larger lateral roots may readily develop above the infection. The most critical period for root-rot infection is from mid-July to late August. Heavy rains during this period cause rapid root-rot spread, resulting in low yields of cotton. Those years with the highest root-rot loss were 1928 with a loss of 89.5% and rainfall of 14.1 inches from June to September, inclusive; 1933 with 92.2% loss and 12.33 inches rainfall; 1935 with 78.4 percent root rot and 19.55 inches rainfall; 1936 with 81.7 percent root rot and 16.99 inches rainfall and 1937 with 72.2 percent root rot and 7.95 inches fainfall. Although 1937 had only about half the total rainfall of most of the other years, 7.35 of the 7.95 inches came in July. From a study of rainfall and root-rot losses over a period of eighteen years at San Antonio, Texas, Ratl'ffe found that root-rot infection appeared to be closely correlated with available soil moisture (16).

These data bear out the assumption that heavy midsummer rains usually result in a rapid spread of root rot in a susceptible crop such as cotton in an infested area. Early planting of cotton reduces the yield loss from root rot under such conditions, although the number of plants actually killed may be relatively high, since such plants mature a number of bolls before they are killed by the disease. An exceptionally early-maturing variety would alleviate losses in yield from root rot in those years when rainfall is such as to cause early and intensive spread of the disease.

Studies on Cotton Root Rot Sclerotia

As previously stated, root rot is perpetuated or carried over from season to season by infected roots and by sclerotia. The infected roots (such as cotton), and possibly mycelial strands remaining after root decay (12, 15) are important as a source of reinfection for relatively short periods of time—possibly one or two years; whereas sclerotia may serve as a source of infection immediately, or for many years after they are

Table 1. Rainfall as Affecting Spread of Root Rot During the Growing Season

Year	June					July				
	Days With Rainfall			Total Rainfall in Inches	Percent of Root Rot Average*	Days With Rainfall			Total Rainfall in Inches	Percent of Root Rot Average*
	0–.5"	.5"–1"	Over 1"			0–.5"	.5"–1"	Over 1"		
1928	3	1	2	3.62	5.9	5	0	1	5.44	22.5
1929	3	0	0	.37	.3	4	0	1	1.75	10.3
1930	3	0	0	.35	.5	3	0	0	.21	7.2
1931	5	2	0	1.62	.8	3	0	1	1.84	8.0
1932	3	2	1	3.08	----	3	1	0	.99	11.2
1933	1	0	0	.08	10.2	2	0	2	5.52	15.1
1934	1	0	0	.10	1.8	5	1	0	1.31	11.9
1935	5	2	3	8.72	----	7	2	0	2.55	----
1936	3	0	0	.62	3.3	5	1	2	7.35	----
1937	5	1	0	1.93	10.5	3	0	2	3.75	31.6
1938	4	1	2	3.28	5.4	9	1	0	1.96	11.9
1939	4	1	2	3.87	5.2	5	0	0	.96	26.2
1940	7	2	3	8.51	3.4	4	1	1	3.09	20.8
1941	11	0	3	6.25	0.0	4	0	1	3.80	4.2

Year	August					September					Total Rainfall, 4 Mo. Period
	Days With Rainfall			Total Rainfall in Inches	Percent of Root Rot Average*	Days With Rainfall			Total Rainfall in Inches	Percent of Root Rot Average*	
	0–.5"	.5"–1"	Over 1"			0–.5"	.5"–1"	Over 1"			
1928	2	2	0	1.46	62.9	5	3	1	3.58	89.5	14.10
1929	1	0	0	.31	26.2	3	0	1	1.57	41.4	4.00
1930	2	1	1	2.55	10.6	2	0	2	2.79	18.7	5.90
1931	3	0	0	.29	23.2	2	0	0	.38	25.0	4.13
1932	6	1	0	1.24	19.9	8	1	2	3.96	36.8	9.27
1933	3	0	1	1.86	67.0	4	0	1	4.87	92.2	12.33
1934	1	1	0	.95	26.4	4	0	0	.69	42.8	3.05
1935	2	3	0	1.33	----	6	2	3	6.95	78.4	19.55
1936	2	1	0	.81	62.5	5	0	4	8.21	81.7	16.99
1937	7	0	0	.64	59.4	3	0	1	1.63	72.2	7.95
1938	2	0	0	.37	25.4	1	0	1	1.38	31.2	6.89
1939	9	1	0	1.52	41.5	2	0	0	.12	49.9	6.47
1940	3	0	0	.38	41.5	2	1	0	1.29	49.1	13.17
1941	6	0	1	2.70	24.9	5	0	0	.44	45.1	13.19

*[illegible] month average for plots planted continuously to cotton. Root-rot data to 1937 were [illegible] by H. E. [illegible] and P. F. [illegible]

formed (4, 5, 19, 21, 23, 24). The highly infective nature of sclerotia has been recognized since they were first described by King and Loomis (10) and Neal (13). Sclerotia are light brown to dark brown in color and vary in size from about .03 to .25 of an inch in diameter, averaging about the size of an okra seed. They are formed singly or in groups throughout the soil at various depths (11, 24) as bead-like swellings in the mycelial strands (Fig. 5).

Figure 5. Formation of sclerotia in chains or bead-like enlargements of mycelial strands as they are produced in infested soil.

Since sclerotia constitute one of the main sources of reinfection for cotton root rot, it is important to know what effect any given treatment has on this stage of the fungus, in addition to its effects as measured by above ground killing of cotton plants. Since equipment (18) was devised for the rapid separation of sclerotia from soil, an effort was made to determine the population and viability of sclerotia in various field areas which had different crop or soil treatments. Beginning in 1933, and up to 1939, soil samples for sclerotial analysis were taken to a depth of only 3 feet and the soil analyzed in 1-foot depth intervals. After 1939 the depth of taking samples varied from three to as much as eight feet, and in some cases the samples were analyzed by six-inch depth intervals.

Population and Viability of Sclerotia From Areas Cropped Continuously For an Eleven-Year Period

Different plots on the Station farm have been planted continuously to corn, oats, sorghum and cotton since the Station was established in 1928. Soil samples for sclerotial analysis were taken from these areas at three different periods in 1938 and 1939. Table 2 shows the average of the total number, number viable, and percentage viability of sclerotia per acre foot in these different areas for the three dates. It will be noted that although the area planted continuously to cotton had both a higher population of sclerotia and a higher percentage of this population in a viable state, the areas planted continuously to grain crops still had rela-

tively large quantities of viable sclerotia. Comparatively few sclerotia were found at depths greater than three feet in any of the areas sampled. The area planted continuously to corn showed a higher population (although somewhat lower viability) of sclerotia than any of the other grain areas. The total number of sclerotia obtained from samples taken at the three different dates varied somewhat, due in a large measure, to the manner in which they are formed in the soil. Sclerotia have a tendency to form in groups or compact chains of from few to several hundred, which may occupy only a few cubic inches of soil. Under ordinary field cropping practices where infection is present, such groups of sclerotia occupy a small fraction of the total soil volume—probably much less than one percent. For this reason it is necessary that sampling be done on a fairly extensive scale in any given area, if reliable data are to be obtained.

Table 2. Number* and Viability* of Cotton Root Rot Sclerotia From Areas Planted Continuously to Corn, Cotton, Oats, and Sorghum for 11 Years Beginning 1928

Crop	Depth, Feet	Number Sclerotia		Percent Viable Sclerotia
		Found	Viable	
Corn	1	957	790	82.3
	2	3513	2298	65.4
	3	2928	1309	44.7
	4	83	39	46.7
	5	643	643	100.0
	Total	8124	5079	62.5
Oats	1	1660	1245	75.0
	2	2889	1949	67.5
	3	661	347	52.5
	4	469	330	70.4
	5	31	8	27.3
	Total	5710	3879	67.9
Sorghum	1	1864	1098	58.9
	2	3300	2764	83.8
	3	1048	749	71.4
	4	22	6	25.0
	5	28	22	80.0
	Total	6262	4639	74.1
Average (grain crops)	1	1494	1044	69.9
	2	3234	2337	72.3
	3	1546	801	51.3
	4	191	125	65.2
	5	234	225	96.1
	Total	6699	4532	67.6
Cotton	1	1413	1231	87.1
	2	3519	2836	80.6
	3	2910	2528	86.9
	4	649	530	61.6
	5	105	75	71.1
	Total	8596	7200	83.8

*Figures for Number of Sclerotia are in terms of thousands per acre for each interval (acre foot).

The sclerotia obtained from all of these areas varied in color from a light brown to a dark brown or with a blackish appearance. In general, the lighter colored sclerotia germinated more readily than the dark-

colored ones. There is good reason to believe that fairly large quantities of sclerotia were recently formed in the soil cropped continuously to cotton, but these new sclerotia could not be distinguished by any external characteristics from older sclerotia formed possibly a year or more before. Inasmuch as it is generally understood that the presence of susceptible plant roots are necessary for continued formation of sclerotia, it is quite evident that sclerotia may live in the soil for long periods of time, as shown by the fact that large quantities of viable sclerotia were obtained from these continuous-grain areas. All of these crops were kept free of susceptible weeds so that any sclerotia present in the grain-cropped areas were produced prior to the time that these continuous-cropping experiments were started. Although there were usually more than a million viable sclerotia per acre foot of soil, only a single sclerotium is necessary for starting a center of infection that might spread as much as 25 feet or more radially through the crop during the growing season. Sclerotia are known to remain viable over as long a period as 7 or 8 years, even when stored under artificial conditions (5, 19, 24, 26). It is logical to assume that viability would be maintained by sclerotia over a much longer period of time where they are not disturbed.

Any crop or soil treatment that reduces the percentage of crop plants killed to any great extent should be followed by an examination of the soil to determine what effect those treatments have had on the sclerotial population. It is hardly conceivable that any ordinary treatment given the upper 6 or 8 inches of soil would have any great effect on sclerotia that are formed at depths of two feet or more in such soils as those in the Blackland area.

Population of Sclerotia to a Depth of Eight Feet in Uncultivated and Clean Fallow Areas

In 1938, soil samples for sclerotial analysis were taken in a virgin meadow on the Substation farm. Since a rather large quantity of highly viable sclerotia were obtained as deep as 3 feet, additional samples were taken in 1940, to a depth of 8 feet. According to records obtained, this meadow land (about ten acres) had never been plowed or cultivated in any manner. In the same year, samples were taken to the same depth in another area that had been in clean fallow for approximately eleven years, and in an adjacent area that had been planted continuously to cotton for five years following clean fallow. These samples were analyzed by 6-inch depth intervals and the the results are given in Table 3. In all cases, a few sclerotia were found as deep as 96 inches, but most of them were found in the upper 36 inches of soil. Although grass plants predominated in the native meadow, there were a few species of weeds that are commonly attacked by the root-rot fungus. Among these were sow thistle *(Sonchus asper)*, false dandelion *(Sitilias multicaulis)*, horse nettle *(Solanum carolinense)*, ground cherry *(Physalis mollis)*, Leavenworth vetch *(Vicia leavenworthii)*, Indian blanket *(Gaillardia pulchella)* and a few other susceptible species. Approximately 72 percent of the sclerotia obtained from the uncultivated meadow were viable. Highly

Table 3. Number* and Viability of Cotton Root Rot Sclerotia to a Depth of Eight Feet in Three Different Areas

Depth, Inches	Number Sclerotia Found				Vertical Distribution Percent	Percent Viable Sclerotia			
	Native Meadow Field K	Clean Fallow Acre E-6	Continuous Cotton Acre E-6	Total		Native Meadow Field K	Clean Fallow Acre E-6	Continuous Cotton Acre E-6	Weighted Average
0-6	51	71	43	165	1.4	20.5	90.2	87.1	67.3
7-12	196	462	182	840	7.1	47.3	89.4	80.9	77.4
13-18	220	1021	1030	2271	19.3	83.6	92.0	70.1	81.2
19-24	512	940	463	1915	16.2	88.6	81.3	85.9	84.3
25-30	363	836	2080	3279	27.8	59.8	94.2	84.1	84.0
31-36	171	238	517	926	7.8	78.2	93.0	87.9	86.6
37-42	76	196	110	382	3.2	74.3	98.6	94.9	92.4
43-48	37	1639	37	1713	14.5	71.7	95.0	88.9	94.3
49-54	28	61	11	100	.8	72.5	52.3	100.0	68.0
55-60	65	15	1	81	.7	85.1	90.9	0.0	85.2
61-66	15	1	1	17	.1	50.0	100.0	100.0	58.8
67-72	19	6	8	33	.3	74.1	75.0	66.7	72.7
73-78	4	1	7	12	.1	66.7	100.0	80.0	83.3
79-84	9	0	22	31	.3	46.2	--------	87.5	74.2
85-90	1	1	7	9	.1	100.0	100.0	80.0	88.9
91-96	6	14	3	23	.2	33.3	10.0	100.0	26.1
Total	1773	5502	4522	11797	--------	71.8	90.8	81.8	--------

*Figures for Number of Sclerotia represent thousands per acre for each 6-inch depth interval.

viable sclerotia were previously obtained from another native meadow in Falls County (20).

In the clean fallow area on acre E-6, no crops had been grown since the summer of 1930. The entire area was kept free of weeds at all times. As previously stated, it is evidently necessary that roots of susceptible plants be present if new sclerotia are to be formed. The same conclusions can be drawn from results obtained in this area as from those obtained in the continuously-cropped grain plots. That is, sclerotia may remain viable for long periods of time if left undisturbed in the soil. Approximately 91 percent of the sclerotia found in this area at this sampling germinated. A rather large quantity of sclerotia were obtained from a few samples taken from the 43- to 48-inch depth. The adjacent area on acre E-6 that had been planted continuously to cotton had a somewhat lower quantity of sclerotia than did the clean fallow area. Approximately 82 percent of these sclerotia germinated.

Number and Viability of Sclerotia in Miscellaneous Field Plots

A summary of results obtained from sampling in various field areas in addition to those listed in the two preceding sections are given in Table 4. Some of these results have previously been published (20, 21). The main reason for sampling in many instances was to establish the fact that sclerotia were present and to gain some idea as to their relative number and viability. In these respects, sclerotia varied rather sharply from area to area in the different experiments. Some of the variation, especially in regard to viability, during the first year or two of this work was probably due to the technique in handling and testing the germination of sclerotia. Those figures reported for the years 1939 and 1940 are for the first three feet of sample taken at depths of from 5 to 8 feet.

Table 4. Number* and Viability of Cotton Root Rot Sclerotia at Different Depths in Various Field Areas

Acre	Treatment	Date of Sampling	Number of Sclerotia				Percent Viable Sclerotia†			
			1 ft.	2 ft.	3 ft.	Total	1 ft.	2 ft.	3 ft.	Total
A-1	4 year rotation	Apr., 1935	518	933	408	1859	74.8	58.2	23.1	55.2
A-1	4 year rotation	May, 1937	69	253	145	467	54.5	60.0	72.2	63.0
B-1	4 year rotation	Mar., 1935	1710	3089	1579	6378	61.0	65.5	58.8	62.7
B-1	4 year rotation	May, 1937	379	1176	942	2497	17.5	46.6	24.3	38.3
C-1	4 year rotation	Jan., 1935	975	1703	433	3111	48.3	27.1	62.5	37.1
C-1	4 year rotation	May, 1937	25	146	282	[illegible]	21.2	32.8	37.1	34.0
D-1	4 year rotation	Dec., 1934	105	584	432	1121	64.2	43.9	14.9	34.6
D-1	4 year rotation	May, 1937	56	471	980	1507	15.7	83.1	52.0	61.5
E-1	Continuous Cotton	Nov., 1934	1788	3491	1701	6980	59.1	53.9	41.6	53.0
E-1	Continuous Cotton	June, 1935	551	4842	2185	7578	77.1	83.0	68.8	75.5
E-1	Continuous Cotton	Mar., 1939	157	2428	833	3418	79.6	67.2	60.5	66.1
E-1	Continuous Cotton	Nov., 1939	1536	2250	655	4441	64.1	78.8	67.9	72.1
A-2	4 year rotation	Sept., 1936	37	2178	1504	3719	41.5	48.5	46.3	47.6
A-2	4 year rotation	Sept., 1938	21	814	619	1454	51.6	66.5	70.0	67.8
B-2	4 year rotation	Oct., 1936	241	1493	1512	3246	48.6	31.0	59.3	45.5
B-2	4 year rotation	Oct., 1938	98	483	352	933	54.9	48.4	55.3	51.7
C-2	4 year rotation	Oct., 1936	448	1195	1162	2805	39.3	10.8	9.8	15.0
C-2	4 year rotation	Oct., 1938	466	1110	504	2080	36.3	12.8	10.7	17.6
D-2	4 year rotation	Oct., 1936	72	1402	2024	3498	82.9	53.5	34.1	42.2
D-2	4 year rotation	Oct., 1938	458	731	817	2006	38.0	27.3	10.7	23.0
D-3	Continuous Cotton	Dec., 1936	1	183	2195	2379	0.0	64.4	55.0	55.7
D-3	Continuous Cotton	Jan., 1937	14	713	2507	3234	100.0	88.3	90.3	89.9
G-2	Clean Fallow	Apr., 1936	238	1237	1307	2782	26.2	11.7	35.3	24.0
H-2	Subsoiling and Sorghum	Sept., 1934	1345	508	1293	3146	25.6	[illegible]	[illegible]	31.5
H-2	3 years Continuous Sorghum	Mar., 1937	121	193	516	830	14.4	62.4	55.9	51.4
Native Meadow, Falls Co.		May, 1935	63	250	336	649	80.8	[illegible]	93.0	[illegible]
Native Meadow, SCS Farm		Sept., 1938	193	2108	[illegible]	2308	92.7	84.9	91.0	[illegible]
Native Meadow, SCS Farm		Feb., 1940	247	731	[illegible]	1511	41.9	87.1	64.1	71.6

D 5	2 year rotation	Apr., 1937	356	1253	2220	3829	67.9	62.7	71.9	68.5
E-5	2 year rotation	May, 1937	454	1985	1264	3703	34.7	68.9	50.1	58.3
F 5	3 year rotation	Oct., 1936	992	1052	1495	3539	54.6	30.6	48.9	45.1
G 5	3 year rotation	Nov., 1936	1586	9005	4907	15498	65.7	70.9	68.3	69.5
H-5	3 year rotation	Jan., 1936	2397	8684	4226	15307	31.5	52.8	57.4	50.8
C-6	2 year rotation	Apr., 1939	166	2535	1061	3762	54.4	70.2	41.3	61.4
D-6-1	2 year rotation	June, 1939	413	5818	3308	9534	38.3	63.9	31.2	51.4
D-6-2	2 year rotation	June, 1939	1065	532	225	1822	18.2	40.1	48.1	28.3
D 6 3	2 year rotation	June, 1939	2066	3472	3575	9113	81.0	55.9	80.0	71.7
D-6-4	2 year rotation	June, 1939	1356	3078	366	4800	88.8	65.2	46.2	70.4
G 6	2 year rotation	Mar., 1939	595	1505	1389	3489	63.5	58.4	61.0	60.3
H-6	2 year rotation	May, 1939	249	770	2706	3725	86.9	41.2	39.8	43.3
F-6	Continuous Corn	Jan., 1938	1675	5125	460	7260	77.5	51.6	43.4	57.1
F-6	Continuous Corn	Aug., 1938	688	3921	4897	9506	88.7	73.3	58.0	66.5
F-6	Continuous Corn	Sept., 1939	510	1492	3428	5430	90.2	92.2	25.9	50.2
F-6	Continuous Oats	Feb., 1938	546	4151	771	5468	37.6	56.6	26.6	50.5
F-6	Continuous Oats	Aug., 1938	3874	3167	333	7374	81.1	79.6	85.0	80.6
F-6	Continuous Oats	Sept., 1939	560	1348	879	2787	69.3	72.4	62.8	68.8
F-6	Continuous Sorghum	Feb., 1938	2884	3472	1547	7903	93.7	75.6	86.7	84.4
F-6	Continuous Sorghum	Aug., 1938	6	2906	200	3112	100.0	92.2	27.8	88.1
F-6	Continuous Sorghum	Sept., 1939	2701	3522	1398	7621	21.8	84.9	60.7	58.1
F-6	Continuous Cotton	Feb., 1938	2476	5508	5534	13518	94.0	77.8	93.5	87.2
F-6	Continuous Cotton	Aug., 1938	832	2892	1434	5158	88.0	81.6	64.2	77.8
F-6	Continuous Cotton	Sept., 1939	930	2158	1764	4852	67.8	86.4	84.4	82.1
E-6	Continuous Clean Fallow	Feb., 1937	1034	5276	2348	8658	53.1	31.2	27.9	32.9
E-6	Continuous Clean Fallow	July, 1938	807	1546	173	2526	41.2	60.1	68.0	54.6
E-6	Continuous Clean Fallow	Aug., 1940	530	1961	1075	3566	89.5	86.8	93.9	89.4
	Grand Total		43608	125127	80811	249546	62.8	62.5	56.9	60.7
	Percent of Total		17.5	50.1	32.4	100.0				

*Figures for Number of Sclerotia represent thousands per acre for each depth interval.
†Percent viable sclerotia figures in this table were calculated before rounding-off into thousands.

A summary of results of sampling in these areas shows that 17.5 percent of the total number of sclerotia were from the first foot, 50.1 percent from the second foot, and 32.4 percent from the third foot. The percentage of viable sclerotia from each depth followed closely the percentage of total sclerotia from each of the three depths. All of the areas on the Substation listed in Table 4 have been planted to cotton some time in the past and are known to have had fairly large percentages of the plants killed in some years. Results of sampling in these areas show that an abundance of sclerotia for reinfection is present. The lower population of viable sclerotia in the four-year rotation (cotton-sorghum-corn-oats) on acres A-1 to D-1, as compared to the continuous cotton acre E-1, would indicate that this rotation, where the frequency of cotton on the same land is only once in four years, is beneficial in this respect. It is very doubtful, however, that grain crops actually have sufficient deleterious effect on sclerotia in the soil so as to reduce the number of sclerotia present within relatively short periods. Certainly, few or no new sclerotia are formed in the presence of the grain crop. On the other hand, it is quite conceivable that the presence of cotton would tend to reduce the number of viable sclerotia present at the time of planting by providing a stimulus, through root excretions or otherwise, for germination and dissipation of sclerotia. Of course many new sclerotia may, in turn, be deposited as a result of root infection by a single sclerotium. Approximately a 15 percent increase in germination was obtained in some preliminary laboratory tests by soaking the sclerotia for a few minutes in water in which cotton seedlings had been grown for a few days, as compared to soaking in pure water or water in which sorghum seedlings were grown. The water in each case was evaporated to one-third of the original volume and filtered through a Mandler filter.

The viability of sclerotia after extended periods and their occurrence in rather large numbers and at great depths in infested areas would almost prohibit the complete eradication of root rot from such areas. The problem then would be one of increasing returns by application of recommended farming practices, even though root rot may not be entirely eliminated.

In addition to those results shown in Table 4, another area on acre H-1 of the Substation that had been in continuous grass for five years was sampled in July, 1939. These samples were taken to a depth of four feet. The population per acre foot for each depth was as follows: For the first foot, 65,000; for the second foot, 100,000; for the third foot, 168,000; and for the fourth foot, 19,000. In the first foot of soil, 57.4 percent of the sclerotia were viable, and 45.8, 24.8 and 85.7 percent were viable from the second, third and fourth foot, respectively. A total of 352,000 sclerotia were obtained, and 142,000 or 40.3 percent were viable. These figures show that there were comparatively few sclerotia in this area. There was little root rot in the susceptible crops, especially in the cotton, that were planted on this area prior to the time the grass plots were established in 1934, indicating that there was a limited quantity of

viable sclerotia present before planting to grass. In 1939, when the area was replanted to cotton, only 6.6 per cent of the plants were killed by root rot at the end of the growing season. This would seem to show further that sclerotia are found only when roots of susceptible plants are present in the soil, so that the fungus may attain a state of active growth, and the extent of infection or root-rot loss may be correlated to some degree with the population of viable sclerotia.

Structure and Composition of Viable and Non-Viable Sclerotia

Histological examinations were made of light-colored sclerotia, recovered from field soil samples, that began germinating within 24 hours after placing in a moist chamber and incubating at 25°C. Similar studies were made of dark-colored sclerotia, also obtained from the field, that failed to germinate after 30 days (non-viable) under the same conditions. Specimens of both viable and non-viable sclerotia were fixed in formalin-alchol-acetic-acid mixture, washed, dehydrated, embedded in paraffin, sectioned with a rotary microtone, stained with safranin and hematoxylin and de-stained with clove oil to which orange G had been added. Sclerotia usually have a well-defined epidermis of two or more layers of cells with thickened walls. The remainder of the internal structure is a compact homogeneous mass of parenchyma-like cells with walls common to adjacent cells. In the case of highly viable sclerotia (Fig. 6), the epidermis had comparatively few layers of cells with thickened walls, usually not more than 2 or 3 cells thick. The thickness of the epidermal layer, however, was not constant over the entire surface of any given sclerotium. It was only one or two cells thick at one location and five or more cells thick at another location. In most cases, there was some cytoplasm in these epidermal cells of the viable sclerotia. The internal cells always had a very dense, readily stained cytoplasm. The non-viable sclerotia (Fig. 6A) had a much thicker epidermal layer of thicker-walled cells than the viable sclerotia. These cells were usually devoid of cytoplasm except those towards the interior. The internal cells contained cytoplasm that was not so dense as similar cells of the highly viable sclerotia. There was apparently some sloughing-off of masses of epidermal cells of the non-viable sclerotia. This is possibly one way in which sclerotia finally decompose. The thickening of cell walls toward the interior apparently continues for a long period after formation of sclerotia.

Microchemical tests (6) indicate that the cell walls of both viable and non-viable sclerotia are suberized since they gave a positive reaction to the phellonic acid test. It was thought that the dark brown or cinnamon-colored pigment might be tannin, but no positive microchemical test for this compound was obtained. It is quite likely that this pigment is a product of oxidation processes in the outer cells. Some of the internal cells of the non-viable sclerotia gave a positive reaction to the iodine-potassium-iodide microchemical test for starch. Cellulose appeared to be a main constituent of the cell walls of sclerotia, since a positive reaction was obtained for the copper-oxide-ammonia test. The cytoplasm

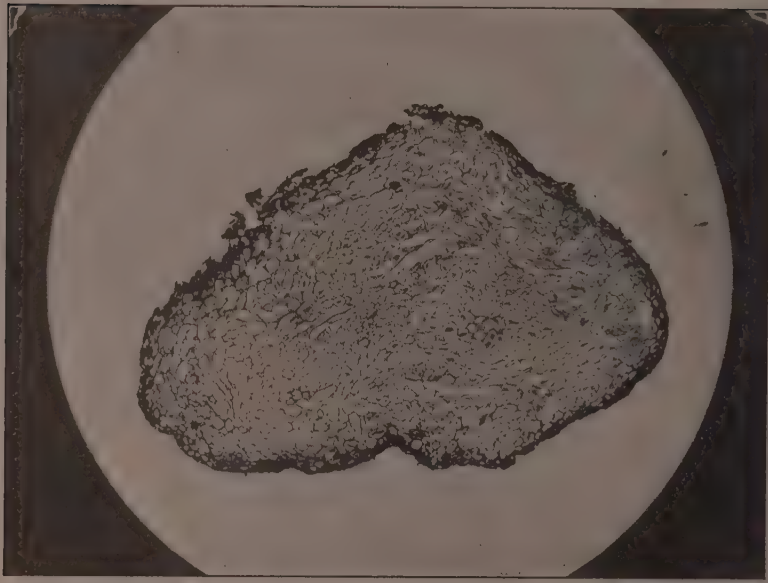

Figure 6. Cross section (X 55) of a viable sclerotium of the cotton root rot fungus, *Phymatotrichum omnivorum.* **Compare with non-viable sclerotium (Fig. 6A.)**

gave a positive reaction to Millon's reagent, indicating the presence of protein. For making microchemical tests, fresh sclerotia were sectioned freehand or with a sliding microtome with freezing attachment and the tests were made immediately.

Light-colored, smooth-surfaced sclerotia are usually viable and germinate or resume growth by producing tufts of mycelium within 1 to 5 days after placing in a moist chamber, or under other suitable conditions. Sclerotia that are dark or blackish in color, lusterless and rough-surfaced are non-viable in most cases. These differences, however, are not sure criteria for judging between viable and non-viable sclerotia. Size or shape has nothing to do with viability, since the shape in a large measure is determined by the shape of soil particles or aggregates immediately surrounding the sclerotia, and the pressure of the soil in which they are formed. In studies previously reported (24), it was found that sclerotia formed at comparatively high temperatures may be of a dark amber color from the beginning, and the color may increase in intensity so that they are dark brown within a fairly short time. When they are formed at low temperatures of approximately 15°C., or lower, they may be of a whitish or cream color and remain light-colored as long as the temperature remains low. It has been thought that sclerotia formation takes place mainly in the fall, primarily for the reason that light-colored ones are

Figure 6A. Cross section (X 80) of a non-viable sclerotium of the cotton root rot fungus. Note thicker epidermis of dark-stained cells and the lightly-stained cells of the interior as compared with the viable sclerotium in Figure 6. (The cracks are probably due to progressive disintegration from one side of the sclerotium.)

sometimes found more frequently at that time. Cooler soil temperatures probably account for this. Under artificial conditions and over a fairly wide range of temperature, sclerot'a may be formed at any time, provided the growth medium or substrate is suitable (4, 24). The same probably occurs under natural field conditions.

Sclerotia apparently lose their viability slowly under field conditions and may remain in a wholly non-viable state for indefinite periods before final decomposition takes place. Field treatments that would hasten this procedure would aid greatly in attaining root-rot-free conditions.

Infection of Certain Monocotylendonous Plants By the Root-Rot Fungus

In the late summer of 1932, some day lily *(Hemerocallis* sp.) lawn plantings in Temple were examined by the writer and Mr. S. E. Wolff (former botanist at Substation 5), following a report by the owner that the plants were in an unhealthy condition. Upon excavation of these yellowish-green, partially wilted plants, it was found that the cotton root-rot fungus was growing profusely over the roots and apparently rotting

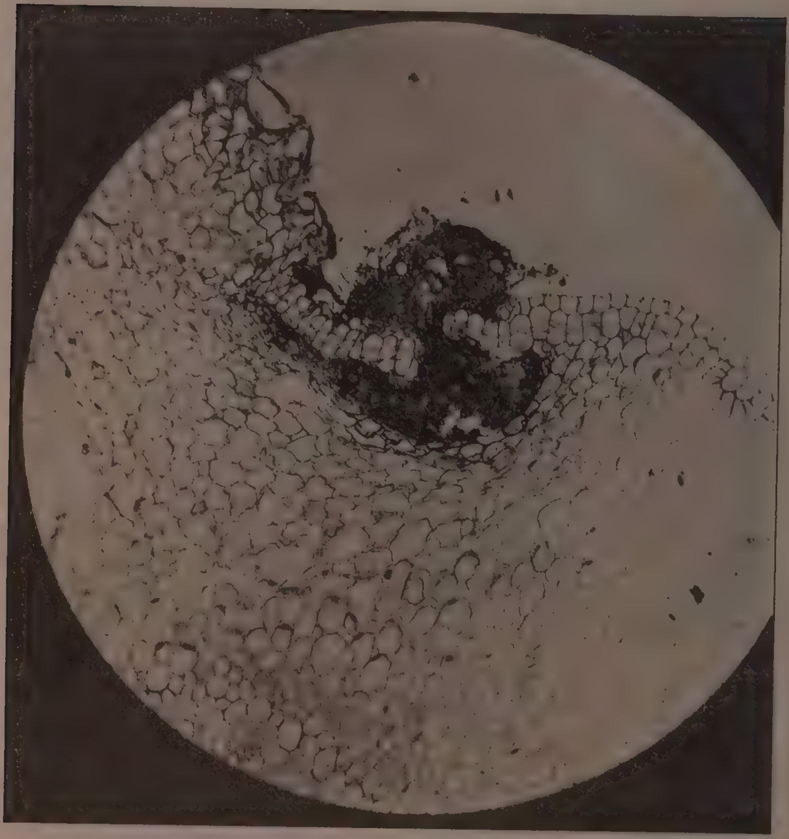

Figure 7. Cross section (X 55) of day lily root showing infection by the cotton root rot fungus. See also longitudinal section (Fig. 7A).

them. These day lilies were in a mass planting approximately 10 feet square, and those that were affected covered an area of about one square yard. The plants nearest the center of the affected area were in a worse condition than those toward the margin of the spot. Some of the infected roots were fixed in formalin-alcohol-acetic-acid fixative, washed in running water, dehydrated, embedded in paraffin, sectioned at from 7 to 10 microns in thickness, and stained with Flemmings triple stain. Upon microscopic examination of tissues taken from the advancing area of the fungus just at the edge of lesions, it was found that there was penetration and decomposition of the epidermal and cortical tissues (Fig. 7, 7A). More attention was given the large, smooth, fleshy lateral roots, since these were somewhat easier to handle than the tuber-like roots. The fungus was penetrating the epidermis in compact masses and collapsing the host cells in the immediate vicinity of the hyphal mass.

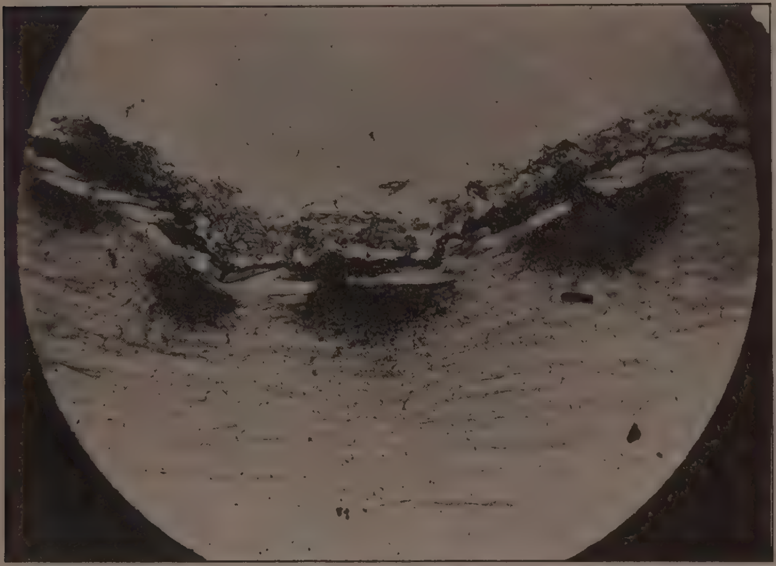

Figure 7A. Longitudinal section (X 55) of day lily root showing infection by the cotton root rot fungus. The mycelium covering the root in the location shown has penetrated the root at a number of points and caused a depressed lesion by decomposing the tissue.

Separate hyphae branched out and penetrated cells some distance away from the large mass of hyphae, which had the appearance of single large strands on the surface, where the hypae entered the epidermis and cortex. Observation of longitudinal and cross sections from other roots showed the same type of infection. In the more advanced stages, the epidermis at and near the point of infection was shrunken and collapsed. The same type of infection and destruction of root tissues, was obtained by inoculating healthy plants with *P. omnivorum* in field soil in the greenhouse, using freshly infected cotton roots as inoculum.

Healthy wandering jew plants *(Tradescantia* sp.) growing under the same conditions in the greenhouse as the day lily plants, were also inoculated with the root-rot fungus. In some instances, the plants seemed to show a reaction by a slight yellowing and wilting. Roots of these plants were examined and distinct lesions were observed, apparently caused by the root-rot fungus, since typical mycelium and large mycelial strands were observed growing over some of the roots. Some of these roots were prepared and sectioned in the manner described above. Microsopical examination of the material revealed epidermal penetration and decomposition of cortical tissues by the root-rot fungus in the same manner as that observed in day lily infections. In another instance, in company with Mr. S. E. Wolff, roots of little blue stem grass *(Andropogon scoparius)* and Yucca *(Yucca rupicola)* that had the root-rot fungus growing freely over them, were excavated in a meadow about five miles southwest of Temple, Texas. Some of these plants had an unhealthy appearance. Along these same lines,

King and Loomis (10) have reported finding the root-rot fungus growing profusely on roots of date palms in Arizona and California and on Bermuda grass, Johnson grass, and sorghum in Arizona. Whether these infections were caused by more virile or pathogenic strains of the fungus in nature, or why in rare instances such monocotyledonous plants may become a host to the root-rot fungus is not definitely understood. As far as is known, however, monocots in general are rightfully regarded as immune to the cotton root-rot disease.

Resistance of Legumes Under Blackland Conditions

Suitable legumes are generally recognized as essential for a balanced farming program where a fairly high degree of diversification is practised. Furthermore, the recently-indicated value of these crops as green manures in root-rot control makes them of unusual importance at this time. In the Blackland, cotton root rot is the limiting factor in the growing of most legumes in the summer, while dry fall weather and peculiar soil conditions are the main limiting factors in growing of winter legume crops. Some varieties of partically all of the commonly grown legumes have been tested, but very few have been found to be adapted to blackland soils under root-rot conditions. Of the many legume species tested at the Blackland Experiment Station, the sweet clovers *(Melilotus* spp.), Sesbania, guar *(Cyamopsis tetragonoloba)* and cowpea *(Vigna sinensis)* have proved most adaptable.

Sweet clovers.—The annual white sweet clover, commonly called hubam, has performed somewhat better in trials than the other sweet clovers and is most commonly grown in the Central Texas area. Sweet clovers have been the most satisfactory legumes from the standpoint of a winter crop, but they leave much to be desired. The plants will withstand temperatures as low as 10° to 15° F., but ordinarily make little growth before spring. Late winter or spring planting may give about the same results in many years as fall planting. The yellow annual sweet clover *(M. indica)* is similar to hubam in growth response on the black soils except that it is somewhat earlier maturing and makes slightly better growth during the winter. The biennial kinds do not usually yield quite so well as the annual species. Unfortunately, root rot prohibits the growing of biennial or perennial legume crops beyond the first year. If sweet clover is to be utilized as a hay crop and cut in early summer, little or none will be lost from root rot. Where the crop is left until late summer for seed production, however, there is a possibility of a large part of the crop being killed by root rot. As in the case of most other crops, this does not mean that those plants that are killed will yield no seed, because this may vary from no yield to a normal yield, depending upon the age of the plants when they succumb to the disease. In some years, from 60 to 75 percent of the hubam clover plants in some fields in the Central Texas area have been killed by root rot.

The sweet clovers, as pointed out later, are proving valuable as soil-improvement crops, as well as of benefit in root-rot control, by simply growing the crops in rotations or plowing them under as green manures. Although some farmers claim that cattle readily eat hubam clover hay

after becoming accustomed to it, the feeding qualities and palatability are not rated very high at present.

Sesbania. This summer legume grows wild over a wide area of Texas, and is highly resistant to the root-rot disease. In the field plot tests at the Blackland Experiment Station, an average of less than 1 percent of the plants were killed, over a period of six years. The crop was produced in most years with no loss. Average yields of seed and air-dry plant material during the same period was 294 pounds and 2654 pounds per acre, respectively. The roots of this plant have a greater abundance of nitrifying-bacteria nodules than any other legume that has been tested. Sesbania has the added advantage of having a moderately high drought resistance. The yield of green matter is somewhat less than that obtained from the sweet clovers, but is sufficient for green-manuring purposes. It has no value whatever as a forage crop since livestock will not eat it. In some new rotations recently started, this crop is utilized as a summer catch-crop for green manure by drilling the seed on oat-stubble land immediately after the oats are harvested. One rain is usually sufficient to produce a crop of plants 3 to 4 feet high by late summer, from seed sown in this manner.

Guar. In the summer legume tests, guar, like Sesbania, has been found to be highly resistant to cotton root rot. Only one variety has been tested thus far, although plans are under way for testing a number of varieties with different growth forms for root-rot resistance and general adaptability. This plant seems to have some qualities for drought resistance, and is a valuable forage plant in Southern Asia, especially in India. In the Blackland soils of Central Texas, guar nodulates rather sparingly and somewhat less than the cowpea. It has been difficult sometimes to obtain good stands in small plots, due to rabbits feeding on the young plants. Over a six-year period, guar has produced an average annual forage yield (air dry) of 2615 pounds and a seed yield of 587 pounds per acre. The annual loss from root rot during the same period was 2.2 percent. Within the last year or two, there has been some demand for guar seed for planting in South Central Texas. If better adapted varieties or strains of guar are developed, they should be of special value in the Blacklands, since the plant is highly resistant to root rot and is useful as a feed for livestock.

Cowpeas. Most of the acreage devoted to cowpea production in Central Texas during recent years has been planted to the blackeye variety. Inasmuch as there is a known resistance to wilt and root knot in the Brabham and Iron varieties, these were planted in a preliminary test along with Blackeye in 1934 to observe whether there might be any difference in resistance to the cotton root-rot disease. A difference in root-rot susceptibility was noted, and in addition to this, the Brabham and Iron varieties were more tolerant of the alkaline Blackland soils, as evidenced by the absence of chlorosis. Chlorosis affects the Blackeye pea seriously, especially after dry hot weather begins in mid-summer. The plots in this test were artificially inoculated two or three times during the season. Seed from the plants that remained alive and green when the pods were mature were planted the following year and the inoculation and

selection procedure repeated for two years. In 1938, these selections of Brabham and Iron were tested for root-rot resistance along with commercial Brabham and Blackeye varieties. Additional varieties were included in the test later.

Table 5 shows the forage and seed yields and amount of root-rot infection for these different varieties for the period in which these data were secured. Root-rot comparisons are not exact since some varieties such as Brabham, Iron and Mozingo mature at a fairly late date and the figures for root rot represent the plants actually dead at harvest time plus those that showed any mycelium on roots adjacent to infection cen-

Table 5. Comparative Root Rot Resistance and Yields of Different Varieties of Cowpeas

Variety	Yield of Forage—lb. per Acre									
	1938		1939		1940		1941		Average	
	Green	Dry	Green	Dry	Green	Dry	Green	Dry	Green	Dry
Blackeye	2805	726	1946	697	5861	1373	9908	1452	5130	1062
Brabham Selection	11484	1716	7754	1800	17054	3934	17711	3262	13501	2678
Iron	14949	2244	7318	2091	14230	3142	9818	2147	11579	2406
Blackeye Cal. 25384	--------	--------	--------	--------	--------	--------	9813	1358	9813	1358
Blackeye Cal. 25539	--------	--------	--------	--------	--------	--------	8208	1863	8208	1863
Black	--------	--------	--------	--------	9689	2218	--------	--------	9689	2218
Brabham	13299	2079	5750	1481	9610	2297	--------	--------	9553	1952
Brabham bush	--------	--------	--------	--------	--------	--------	9439	2052	9439	2052
Brabham vine	--------	--------	--------	--------	--------	--------	16890	3135	16890	3135
Chinese Red	--------	--------	--------	--------	10877	2508	--------	--------	10877	[illegible]
Clay	--------	--------	--------	--------	11880	2666	9787	2084	10834	2375
Conch, Florida	--------	--------	--------	--------	--------	--------	10387	1505	10387	1505
Cream	--------	--------	4298	1191	5834	1320	9250	1542	6462	1351
Iron Selection	--------	--------	6127	1539	12487	2904	10586	2299	9733	2247
Mozingo	--------	--------	--------	--------	12038	2878	16038	2747	14038	2862
Purple Hull	--------	--------	--------	--------	--------	--------	9376	2210	9376	2210
Red Ripper	--------	--------	--------	--------	11299	2561	--------	--------	11299	2561
Whippoorwill	--------	--------	6273	1568	8818	2138	10549	2115	8547	1940
Whippoorwill (Ala.)	--------	--------	--------	--------	9953	2323	--------	--------	9953	2323

Variety	Yield of Seed—lb. per Acre					Percent Root Rot				
	1938	1939	1940	1941	Ave.	1938	1939	1940	1941	Ave.
Blackeye	667	883	631	78	565	62.6	57.5	23.4	2.2	36.4
Brabham Selection	475	35	686	82	319	9.1	24.5	22.8	0.0	14.1
Iron	36	186	1241	410	468	1.0	27.7	18.3	1.9	12.2
Blackeye Cal. 25384	--------	--------	--------	110	110	--------	--------	--------	13.9	13.9
Blackeye Cal. 25539	--------	--------	--------	348	348	--------	--------	--------	9.0	9.0
Black	--------	--------	1035	--------	1035	--------	--------	19.2	--------	19.2
Brabham	478	287	787	--------	517	2.5	36.4	13.1	--------	17.3
Brabham bush	--------	--------	--------	429	429	--------	--------	--------	5.8	5.8
Brabham vine	--------	--------	--------	104	104	--------	--------	--------	0.7	0.7
Chinese Red	--------	--------	520	--------	520	--------	--------	11.0	--------	11.0
Clay	--------	--------	1428	398	913	--------	--------	20.2	0.4	10.3
Conch, Florida	--------	--------	--------	205	205	--------	--------	--------	1.0	1.0
Cream	--------	273	290	161	241	--------	36.8	34.1	1.0	24.0
Iron Selection	--------	151	950	436	512	--------	43.3	21.6	2.0	22.3
Mozingo	--------	--------	84	0	42	--------	--------	26.9	0.7	13.8
Purple Hull	--------	--------	--------	502	502	--------	--------	--------	4.4	4.4
Red Ripper	--------	--------	737	--------	737	--------	--------	17.4	--------	17.4
Whippoorwill	--------	122	737	320	393	--------	31.9	20.2	4.1	[illegible]
Whippoorwill (Ala.)	--------	--------	847	--------	847	--------	--------	22.8	--------	22.8

ters. The early varieties therefore have a comparatively lower root-rot infection than would be the case if all varieties had been harvested at the same t me. In 1938, there was a considerable difference in resistance to root rot between Blackeye and the Brabham and Iron varieties, the Blackeye continuing to be one of the most susceptible throughout the test period. The selection made from the Brabham variety gave the highest average forage yield throughout the test. This selection is more of a vine type which seems to produce a greater amount of forage than the more erect bush type. Over the period of the test, the commercial Brabham and Iron cowpeas had about the same root-rot resistance as the selections made earlier. The Brabham and Iron selections have been planted in general crop areas on the Station farm, and have gone through periods of late summer drought with little or no yellowing. Growth during such periods, however, is at a low ebb. Although more susceptible to root rot and chlorosis, and a comparatively low yielder of forage, the Blackeye cowpea is usually one of the best for seed production and is in great demand as a table crop. Two strains of California Blackeye, reported to be resistant to root-knot nematode injury, were introduced into the test in 1941. The 1941 season was one of a low root-rot incidence, but these two strains had a somewhat higher root-rot infection than any of the other varieties. In the two years that the Clay variety was included in the test, it produced a moderately high forage yield and a comparatively large quantity of seed. The fact that cowpeas are a general purpose legume (used for green manuring or soil building purposes, and for forage and food) should make them a very desirable legume for growing on a large scale on Blackland soils. Experimental rotations are under way on the Substation farm wherein cowpeas are used both as a hay crop and as a green manuring crop.

Rotations and Green Manures as Affecting Root Rot and Crop Yields

The effect of various rotations and crop sequences on cotton root rot has previously been reported for most of the rotation studies undertaken at the Temple Substation (17, 21). Results of these studies confirmed previous reports that long-time rotations, or the planting of non-susceptible crops for at least three years before planting again with cotton, have been the most effective types of rotations for reducing root rot. In the matter of crop sequence, these studies showed that highest yields were obtained where cotton followed corn. In most of the work dealing with crop rotations reported to date, there has been little mention made of the use of green-manuring crops in such rotations. The first use of a crop for manurial purposes on the Substation was made in 1929, when a crop of red top sorghum, amounting to 6.15 tons of green plant material per acre, was disked and turned under in midsummer. Cotton planted on this area in 1930 had 5 percent root rot and yielded 202 pounds of lint per acre, while the cotton planted on an adjoining check area had 16.9 percent root rot and yielded 158 pounds of lint per acre. The cotton bolls on the sorghum plots averaged 7.19 grams, and those on the check plots 6.85 grams seed cotton per boll. The increased cotton yield, however, was not enough to justify sacrificing a cash crop for one year.

During the last three years, a number of new rotations have been started at the Temple Substation, wherein legumes or other crops have been included for utilization as green-manure crops or for the double purpose of providing forage and also some plant residue for incorporation in the soil. Data already obtained from two such rotations are presented in Table 6. These two rotations, of three-year duration, are on a comparatively large scale and occupy 14 acres, including two continuous-cotton check plots. The rotations were designed to stop gullying which had begun some years earlier. Each crop follows contour lines and most of the land in the test has a 4 to 5 percent slope. The same rotation scheme of cotton, corn, and oats is followed in both rotations, except that in one, cowpeas are planted as a summer catch-crop for green manure and in the other rotation sorghum is used for the same purpose. Both the cowpeas and sorghum were planted on oat stubble immediately after oat harvest, and turned under in late summer. The cowpeas yielded an average of 3.12 tons greens (0.54 ton air-dry) material and sorghum yielded 3.09 tons green (1.02 tons air-dry) material per acre annually.

Table 6. Effects of 3-Year Rotations With Summer Catch-Crops of Cowpeas and Sorghum for Green Manure Upon Root Rot in the Succeeding Crop of Cotton

Rotation	Year	Percent Root Rot	Lint Cotton, lb. per Acre
Cotton-corn-oats with cowpeas	1939	19.4	197
Cotton-corn-oats with cowpeas	1940	24.3	172
Cotton-corn-oats with cowpeas	1941	41.3	249
Average		28.3	206
Continuous cotton	1939	46.6	315
Continuous cotton	1940	41.4	131
Continuous cotton	1941	77.6	131
Average		55.2	192
Cotton-corn-oats with sorghum	1939	6.7	211
Cotton-corn-oats with sorghum	1940	37.8	102
Cotton-corn-oats with sorghum	1941	63.3	203
Average		35.9	172
Continuous cotton	1939	60.6	222
Continuous cotton	1940	64.6	100
Continuous cotton	1941	83.0	66
Average		69.4	129

In each of the three years, root rot was considerably less in the rotated-cotton plots of both rotations than in the comparable continuous-cotton areas, although there was a higher yield of cotton on the continuous-cotton plots in 1939 than in the rotated-cotton plots. The factors, other than differential insect infestation, which contributed to this yield difference have not been ascertained. Cotton yields for 1940 and 1941 were higher for cotton in the rotation than for continuous cotton. The average annual lint yield of cotton in the rotation with cowpeas as green manure was 206 pounds per acre as against 192 pounds for the accompanying check, and 172 pounds in the rotation with sorghum as a green manure as compared with 129 pounds for the check plot. Past experience has shown that little advantage is gained from this type of rotation where no green-manure crop is included in the cropping system.

Results obtained from a series of two-year rotations of cotton with corn and hubam clover, begun in 1940, are given in Table 7. The hubam clover crop was utilized in two different ways. In one case, the crop was harvested for hay when the blossoming stage of the plants was about one-third completed, and in the other case, the crop was cut for seed after the plants had matured. There was little or no second growth where the crop was cut for seed, but some second growth was obtained where the crop was cut earlier in the season for hay. Where the crop was left for seed, a large part of the leaves had shed at the time of cutting, probably contributing about as much leafy organic matter for incorporation in the soil as produced by the second growth following harvest for hay. One fact is outstanding—that the root-rot loss in cotton following hubam grown in 1940 was comparatively low, regardless of the manner in which the crop was handled. Yields from cotton following this clover were approximately double that from cotton planted on the same land for the second year. Copies of actual field maps nearest the average for hubam and continuous-cotton plots are shown as the lower two maps in Figure 8. Root-rot percentages and yields of cotton on plots planted to corn the previous year were intermediate between those

Table 7. Effect of Corn and Hubam Clover on Root Rot of Cotton in 2-Year Rotations, 1941 Data

Preceding Crop	Percent Root Rot		Yield Seed Cotton Pounds Per Acre
	Aug. 15	Oct. 1	
Cotton	45.1	70.9	540
Corn	19.5	45.1	792
Hubam (for hay)	11.6	20.0	1015
Hubam (for seed)	8.0	14.6	1110

of the cotton-following-hubam plots and the cotton-following-cotton plots. Each plot in these rotations is one-tenth acre in size and each rotation is set up in quadruplicate. Hubam clover on two plots are harvested for hay and on the other two for seed. A few farmers who have planted hubam clover on root-rot infested land and followed this crop with cotton, report that there was comparatively little root rot in the cotton and that fair yields were obtained. In such instances, however, there were no adjacent areas receiving other treatments with which these fields could be compared.

Effect of Date of Tillage and Destruction of Cotton Stalks On Root Rot

It was noted in 1934 that crop plants grown on land where cotton had been plowed under in 1933, in compliance with Agricultural Adjustment Administration requirements for crop reduction, were much larger than those growing on adjacent areas where the cotton crop had been permitted to

mature. In connection with the cotton root-rot work, an experiment was started in 1940 as a part of a cooperative plan with the Division of Cotton and other Fibre Crops and Diseases, U. S. Department of Agriculture, to determine the effect early turning of cotton stalks would have on root rot as compared to delayed turning—or what might be called the usual farm method of tillage and destruction of stalks. In this experiment the treatments were as follows:

(1) Stalks turned under immediately after picking, and while they were still green, by flat breaking,

(2) Stalks turned early, the same as in No. 1, plus 120 lb. of nitrogen per acre.

(3) Stalks cut early without flat breaking.

(4) Stalks pulled (by hand) early,

(5) Stalks ripped early,

(6) No early treatment (delayed tillage),

(7) No early treatment (delayed tillage), plus 120 lb. of nitrogen per acre.

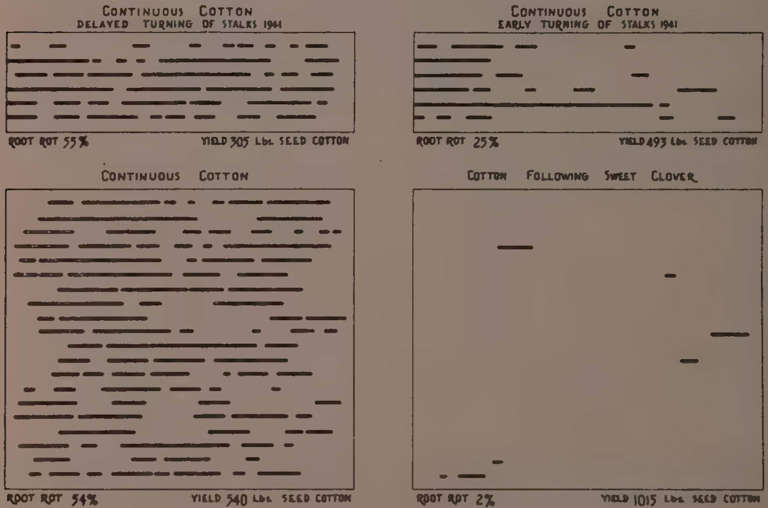

Figure 8. Root-rot maps from two different field experiments. Continuous cotton with delayed turning of stalks and early turning of stalks above and cotton following cotton and cotton following sweetclover (Hubam) below. These are copies of maps, made on August 15, 1941 of actual plots nearest the average for each treatment.

The delayed tillage (No. 6) is the practice commonly employed by farmers, and is used in this experiment as a check or control. The stalks are usually left standing in the field until early- or mid-winter, at which time they have become dry and break readily. The land is then prepared

by bedding without breaking or cutting of the stalks. In some cases the land is flat-broken or the stalks cut before bedding. It is common practice to follow cotton with oats, drilling the grain in the fields in the early fall without cutting the cotton stalks. In this experiment, the flat breaking was done with a moldboard plow to a depth of about 7 inches, and where stalks (including part of tap root and laterals) were ripped this was accomplished with a similar plow without the moldboard. All stalks were left on the plots regardless of treatment. One-half of the nitrogen applied was derived from nitrate of soda and one-half from ammonium sulphate. The mixed fertilizer was broadcast immediately before flat breaking in treatment No. 2, and on the same date on the delayed tillage plots (treatment No. 7.) In the latter case, the fertilizer was left uncovered until the time of bedding in January. All of the early treatments, including the nitrogen applications, were made on September 27, 1940, and all plots bedded with a double moldboard bedding plow (lister) on January 28, 1941. No intervening tillage was given between these two dates, nor between the time of bedding and time of planting on April 9, 1941. Following planting, the crop was handled in the customary manner. The plots are six rows wide (18 feet) by 62 feet long with a two-row sorghum barrier separating plots lengthwise and a sixteen-foot turning space, planted to sorghum, separating the ends of plots. Each treatment is replicated five times and all treatments are randomized over the five blocks.

Results of the test for 1941 are shown in Table 8. The most effective control of root rot and the highest cotton yields were obtained where the plants were turned early by flat breaking. Supplementing this treatment with the 120 pounds of nitrogen per acre provided no extra benefits. Early cutting of the stalks without tillage did not prove beneficial. This might be expected, since it is quite likely that the root-rot fungus continued to grow where live roots were left intact. Ripping out of the stalks as soon as the cotton could be picked was second to early flat breaking in effectiveness. The application of nitrogen where tillage was delayed resulted in some root-rot reduction and increase of yield, but the increase obtained was not sufficient to pay for the cost of the fertilizer used. Copies of actual field maps nearest the average for flat breaking and delayed tillage treaments are represented by the two maps in the upper part of figure 8.

Table 8. Effect of Date of Tillage and Destruction of Cotton Stalks on Root Rot and Yield of Cotton

Treatment	Percent Root Rot		Yield Seed Cotton Pounds Per Acre
	Aug. 15	Oct. 1	
(1) Flat break early	25.7	72.7	493
(2) Flat break early+N	27.4	68.2	378
(3) Stalks cut early	41.3	81.5	303
(4) Stalks pulled early	43.4	87.8	342
(5) Stalks ripped early	30.3	75.7	459
(6) Delayed tillage	41.4	77.6	373
(7) Delayed tillage+N	33.7	74.8	446

Early destruction of stalks by flat breaking should be of value for the following reasons: First, the green stalks and leaves have a greater value in increasing the fertility of the soil than the same stalks after standing in the field until mid-winter; second, there is a fairly large quantity of moisture within the green plant that aids in its decomposition; third, a large part of the root system on which the fungus continues to grow and thrive in early fall is destroyed; and finally, such a procedure is beneficial in insect control.

Subsoiling and Its Effects On Root Rot

Experiments were conducted over a 4-year period from 1930-1933 inclusive, to determine the effects of deep tillage or subsoiling on root rot and crop yields. A No. 25 Killefer subsoil plow and a No. 35 plow of the same design but of much heavier construction were used for most of the deep tillage operations. In addition to these two types, a horse-drawn chisel and a tractor-drawn gang-type chisel plow with a series of chisels were also used in a few tests. These two chisel types reached a depth of only about 10 inches. The No. 25 Killefer operated at a depth of approximately 18 inches, and the No. 35 Killefer operated at a depth of from 25 to 30 inches. Subsoiling operations were usually performed in early fall following crop harvest. The effect of subsoiling on the following cotton crop at a number of different locations on the substation and adjacent areas for four years are shown in Table 9. With very few exceptions, subsoiling always reduced root rot. In some cases, however, yields were not increased and certainly were not increased sufficiently to pay for the cost of such operations. The No. 35 Killefer is an especially heavy draft implement and requires power equal to that of a 50 h.p. Caterpillar tractor. In some instances, it was necessary to break the soil first with the No. 25 Killefer.

These subsoiling operations probably accounted for the destruction of some sclerotia. Where the sclerotia are broken loose in the chains, especially if they are recently formed, they may be subject to the parasitic action of other organisms and decompose readily, or they may germinate and dissipate themselves without forming new sclerotia. Such a reaction has been observed in the laboratory, where sclerotia are artificially produced in soil cultures and then stirred or broken loose from the chains or clumps. Unprotected surfaces which may provide suitable areas for attack by parasites usually remain where the mycelial strands break loose on each side of the sclerotium. The fact that cotton yields were not increased at a rate comparable to the reduction in root rot may have been due, at least in some years or in some locations, to the drying of the subsoil or to looseness of the soil, particularly if rainfall was light following these operations.

King and Loomis (9) reported negative control of cotton root rot in Arizona by subsoiling, whereas Hooton (7), in the northern part of the Texas Blackland Belt, obtained remarkable control by subsoiling.

Table 9. Effect of Subsoiling on Root Rot*

Year	Number of Locations	Percent Root Rot		Yield of Lint Cotton Pounds Per Acre	
		Subsoiled	Not subsoiled	Subsoiled	Not subsoiled
1930	6	22.8	42.4	146	161
1931	14	28.6	46.2	276	207
1932	18	25.6	50.0	182	159
1933	9	45.1	72.8	298	308
Average		32.0	52.8	225	209

*H. E. Dunlavy collected part of the data on these experiments.

Effect of Rate of Planting Cottonseed on Cotton Root Rot

In 1939, some cotton seed treatment studies were made in which seed was planted by hand at the rate of 2, 5, and 10 seeds per hill, in hills 18 inches apart in three-foot rows. The seedlings were thinned later to a common stand of not more than two plants per hill. End-season averages of all tests showed that 15.9 percent of the plants were killed where the planting was at the rate of 10 seeds per hill, 7.7 percent at the rate of 5 seeds per hill, and only 0.6 percent of the plants were killed at the rate of 2 seeds per hill. The same test was repeated in a similar manner in 1940, and in addition, some larger plots were planted on another location with a horse-drawn planter at a heavy rate of planting (10-12 seed per foot) and at a light rate (2-3 seed per foot or per hill). In both cases, the root rot was lower where the thinner rate of seeding was used.

In 1941, the above experiment was repeated and another was undertaken on a still larger field scale in a different area. Seed were planted at three different rates over approximately 20 acres. Each different rate of planting was replicated seven times and occupied altogether approximately seven acres for each rate. Acid delinted (Kem-gas) seed were planted in both areas. In the smaller experiment seed were planted with a single-row horse-drawn planter using corn plates with the proper number of holes to plant 2 or 3 seed per hill and 10 or 12 seed per foot. A hill-drop attachment for a 2-row tractor planter was used for planting the delinted seed on the larger area, and adjusted so that seed were dropped at approximately 18-inch intervals. Six-hole, 12-hole, and 24-hole corn plates provided a planting rate of 2 to 3, 5 to 6, and 10 to 12 seed per hill, respectively. Seedlings were thinned to a common stand of not more than 2 plants per hill in all rates of planting each year. As shown in Table 10, results from this experiment were similar to those in the other tests in that root rot was lower and cotton yields were higher where the rate of planting was reduced. Over 100 pounds more seed cotton per acre were harvested from the thinly planted cotton plots than from the plots thickly planted (10 to 12 seeds per hill).

It is not understood just why such a variation occurs. Plants in the 2-seed-per-hill plots were somewhat larger and more vigorous in appearance

Table 10. Effect of Rate of Planting Cotton Seed on Cotton Root Rot

Seed per Hill	Percent Root Rot								Yield Seed Cotton Pounds per Acre			
	August 15				End of Season							
	1939	1940	1941	Ave.	1939	1940	1941	Ave.	1939	1940	1941	Ave.
10	15.9	22.2	----------	19.1	23.1	42.6	----------	32.9	742	587	----------	665
5	7.0	12.2	----------	9.6	12.0	32.3	----------	17.7	755	663	----------	709
2	.6	9.4	----------	5.0	1.8	31.2	----------	16.5	876	600	----------	738
10–12	----------	75.1	29.7	52.4	----------	84.6	87.1	85.9	----------	96	150	123
2–3	----------	49.0	19.5	34.3	----------	70.3	82.7	76.5	----------	152	183	168
10–12	----------	----------	23.7	23.7	----------	----------	51.3	51.3	----------	----------	380	380
5–6	----------	----------	17.2	17.2	----------	----------	44.9	44.9	----------	----------	436	436
2–3	----------	----------	9.9	9.9	----------	----------	35.8	35.8	----------	----------	493	493

in the early seedling stage than those in plots with a higher seeding rate. Although no detailed root studies were made, it is quite possible that a fairly well developed root system became established more quickly where the rate of seeding was lowest and in this way the plant may have been aided in evading root rot. If this difference would hold true in most years in Blackland soils, as it did during the three years of these tests, such a method of planting would have a further advantage in that the quantity of seed required would be reduced. It takes less labor to handle a cotton crop that has a few plants per hill spaced at a distance of 15 to 18 inches, because it is easier to thin and hoe the crop.

Cotton Yield and Seed Quality as Affected by Date at Which Plants Are Killed by Root Rot

Cotton growers, ginners and oil mill operators have been interested in the quality of seed from fields in which a large proportion of the plants have been killed prematurely by the cotton root-rot disease. Seed from selected cotton plants killed by root rot at semi-monthly intervals from July 15 until the end of the season in 1936, 1937, and 1938 were analyzed for oil and protein. Emergence tests of seed from plants killed on the above dates in 1937, 1938 and 1939 were made in the growing season the following year, and cotton yield from these emergence test plots recorded. Only those plants were used that had succumbed just prior to each semi-monthly date. Cotton was picked from these plants on or about October 1, of each year, at which time samples were obtained from a similar number of plants that were in a normal healthy condition. These samples were taken from two locations each year, and the figures shown in Table 11 represent the averages from these areas.

Estimated cotton yields for each date of killing, based on 100 plants from each of three areas for each date, in 1941 only, are given in the first column of Table 11. Where plants are killed by root rot early in the season, before the bolls are large enough to open and produce a crop, there is very little cotton made on such plants. As the date of killing by the fungus is delayed, the yield of cotton is increased. The relative seasonal advancement (whether early or late) of root rot from infection centers, therefore, to a large measure determines cotton yield, rather than the total end-season amount of root rot. The advancement of root rot along a cotton row, from a center of infection (at right), is shown in Figure 9. No cotton was produced on the first plant killed (mid July), and only two immature bolls opened on the second plant killed in the advancing infection (towards the left). As the date of killing was delayed, more bolls of a better quality opened. There is some fallacy in correlating loss of crop yields with end-season percentage of dead plants, although this final percentage in a large measure, indicates the relative amount of root rot that might be present at any given date during the earlier part of the season. Climatic conditions may alter the relationship of yield to root rot considerably ,so that the final root-rot condition in any given field is not necessarily indicative of the yield from that par-

Figure 9. Spread of root rot along a cotton row from a center of infection (right). The first plant was killed in mid July and the photograph taken on September 11. The plant at the extreme left exhibited no external symptoms of root rot, while the plant adjacent to this green one had been dead about three days at the time of photographing. Plants killed late in the season may produce a normal yield.

ticular field. Ordinarily, about August 15 (middle of the fruiting season), is one of the most critical periods insofar as root-rot infection directly affects the yield of cotton. The yields will also vary over a wide range, depending on the earliness of the crop, which in turn will determine to a large extent the number of grown bolls on the cotton plants at any particular time during mid-season, when root-rot infection might take place. These studies emphasize the importance of soil treatments that would delay the appearance or spread of root rot in a field.

The oil content of the seed from the plants killed at different dates (Table 11) varied from approximately 10 percent to about 17 percent of the seed weight between plants killed early in the season and those remaining green on October 1. The protein content varied over a much narrower range, usually from about 20 to 22.5 percent of the total weight of the seed. In most cases, the difference between extremes was approximately 2.5 percent. The larger part of the seed from plants that succumbed early in the season were non-viable, being light and only partially filled. Seed emergence varied from about 10 percent, for seed from plants killed on July 15, to 70 percent for seed from plants remaining green at the end of the season. The difference in quality of these lots of seeds was further reflected to a certain degree in the yield. However, in those cases where enough seed germinated to produce a fair-

Table. 11. Effect of Age of Cotton Plants at Time of Death From Root Rot on Yield, on the Composition of Seed, and on the Emergence and Yield From the Seed Produced

Date Plants Killed	Yield Seed Cotton, lb. per Acre	Composition of Clean Seed—Percent											
		Moisture				Protein				Oil			
		1936	1937	1938	Ave.	1936	1937	1938	Ave.	1936	1937	1938	Ave.
July 15	8	11.38	7.43	10.30	9.70	18.19	20.81	19.56	19.52	8.88	10,53	9.53	9.65
Aug. 1	22	11.50	7.15	10.30	9.65	18.50	22.19	20.41	21.03	9.73	14.59	9.63	11.32
Aug. 15	135	10.90	7.83	9.00	9.25	20.13	22.65	22.16	21.65	12.12	14.25	14.88	13.34
Sept. 1	498	10.70	7.39	9.10	9.06	20.81	22.25	22.56	21.87	14.04	16.42	15.29	15.25
Sept. 15	674	10.80	7.51	8.60	8.97	20.94	22.88	22.38	22.07	15.54	17.29	18.22	17.02
Green*	1252	10.14	7.21	8.80	8.72	20.41	22.48	22.56	21.82	15.78	17.73	17.91	17.14

Date Plants Killed	Seed Performance							
	Emergence Percent				Yield Seed Cotton Pounds per Acre			
	1938	1939	1940	Ave.	1938	1939	1940	Ave.
July 15	4.2	11.5	12.8	9.5	176	352	205	244
Aug. 1	6.3	11.5	37.0	18.3	495	308	684	496
Aug. 15	34.2	46.9	62.3	47.8	655	836	878	790
Sept. 1	56.8	63.3	67.2	62.4	641	1056	542	749
Sept. 15	68.2	68.2	71.2	69.2	567	1078	800	815
Green*	73.3	75.0	57.9	68.7	501	1122	742	788

*Plants remaining green on October 1.

ly good stand of plants, there was no difference in yield although the emergence differences may have been fairly great. In other words, if from 35 to 50 percent of the seed normally planted germinate and produce healthy seedlings, this is sufficient to give a good stand of plants which will produce a normal crop of cotton, since the larger part of the seedlings are ordinarily removed in thinning.

It is quite possible in years when there is a rapid spread of root rot at the time when plants had a large number of immature bolls but very few grown bolls (as in 1941), that a poor quality of seed would be expected. This, along with heavy insect infestations, no doubt accounted for the fact that the 1941 seed crop, produced in most Blackland areas, had an unusually low germination. The same thing would apply in any season if seed for planting purposes are taken from an area that had an early and widespread damage from root rot. During a number of recent years there has been a severe mid-season spread of root rot. Oil mill operators have reported that seed from areas where root rot infestations are generally severe is of a much lower quality than seed from areas with a low root-rot incidence within the same county or district.

Chemical Soil Treatment For Root-Rot Control

A wide variety of chemicals have been tried as soil fungicides for the control of root rot but none has proved of any great value in Blackland soils. Penetration of these highly colloidal soils by most soil amendments proceeds at a very slow rate under normal conditions. In order to eliminate all of the sclerotia in infested soils, for example, it would be necessary for the fungicide to reach a depth of at least four or five feet, either by penetration or actual placement of the material in the soil to these depths. This latter method of application of various chemicals has been used at the Temple Substation in a limited manner in experiments designed to control root rot of roses and cotton.

It was found in earlier laboratory tests (22) and confirmed later (2) that copper sulphate (blue vitriol) was more toxic to the cotton root-rot fungus at comparatively low concentrations than certain other common salts of metals such as iron, zinc, aluminum and mercury. Effective use of copper sulphate for root-rot control of citrus in the Lower Rio Grande valley has been reported by Bach (1). Ammonium sulphate has likewise been reported to have given good results when used under certain conditions for root-rot control (25). As a matter of fact, soil acidifying materials, especially sulphur and sulphur compounds, have probably been used to a greater extent in attempts to control this disease than any other chemicals. While it is a well-known fact that an acid soil condition inhibits growth of the fungus, it has not been possible to acidify the Blackland soils even with very large applications of acidifying materials, such as sulphur. The material from which some of the Blackland soils are derived is calcareous in nature, making it practically impossible to increase the acidity. In those areas where success has been obtained with soil amendments, the soil is coarser textured than the Blackland soils even though some of them may be relatively alkaline.

An experiment was begun in 1940 wherein some of the soil fungicides were thoroughly mixed with the upper foot of soil in plots where test plants were to be grown. Soil was removed to a depth of one foot in a series of plots 9 by 11 feet in size, and refilled with the same soil in which various materials or combinations of these materials as shown in Table 12 were thoroughly mixed. Roses were used as test plants for two reasons: they are highly susceptible to the cotton root-rot disease, and in most instances, show a high degree of chlorosis when planted in the Texas Blackland soils. It was planned to determine the effects of these soil treatments on both root rot and chlorosis. Copper sulphate, ammonium sulphate and two different types of soil sulphurs were used alone and in combination with iron (ferrous) sulphate in these plots. Nine rose bushes (two-year-old Talisman) were planted on each plot and each treatment was made in quadruplicate and randomized over the area. Blooms were clipped at weekly intervals, the number per plant recorded throughout the growing season, and the general vigor and reaction to root rot noted. The plants that were killed in 1940 were replaced in February 1941, but no additional chemicals were added to any of the plots. The roses were interplanted with cotton as an inoculator plant between the rows which were 4 feet apart, with the bushes spaced at 3-foot intervals in the rows. Thus, there was 2 feet between each row of roses and each row of the interplanted cotton. As soon as freshly infected cotton roots were available in the field, the cotton plants in each plot were inoculated and irrigated. At the first inoculation only two spots were so treated on each row of cotton in each plot. Further inoculations were made later in the season, if any cotton plants survived. In previous work of this kind, the plants to be tested were inoculated. However, due to the rather severe nature of the inoculation treatment, this was discontinued and an inoculator plant, such as cotton, was interplanted with the test plants in each experiment. More recently, fleshy-rooted and highly susceptible plants, such as carrots or beets, were interplanted and used as inoculator plants. Results for the 2-year period indicate that a mixture of two ounces each of copper sulphate, iron sulphate, and soil sulphur per cubic foot of soil was most effective in controlling root rot and increasing the vigor of the plants. The number of blooms cut from the plants receiving this treatment was somewhat higher and the blooms possibly were of a little better quality than those from plants receiving other treatments. Plants growing on these plots also showed somewhat less chlorosis than did plants on other plots. The soil sulphurs used alone at eight ounces per cubic foot of soil reduced chlorosis somewhat. Recently, one or two commercial pest-exterminating companies have told the writer that this combination of copper sulphate and iron sulphate was very effective in reducing root rot in lawn shrubs, such as the Ligustrums, in sandy-clay soils of the East Cross Timber region.

Inasmuch as crude oil has been used effectively as a barrier (10) in preventing spread of root rot from infested to non-infested areas, field

Table 12. Effect of Various Soil Treatments on Bloom Production and Root Rot of Roses

Treatment	Rate—oz. per cu. ft.	Number of blooms per plant—Av.		Percent Root rot	
		1940	1941	1940	1941
(Copper sulphate Iron sulphate)	5 5	45	46	8.3	1.2
(Copper sulphate Iron sulphate)	2 2	51	41	16.6	0.8
(Copper sulphate Iron sulphate Soil sulphur)	2 2 2	46	50	0	1.2
Copper sulphate	2	50	39	2.8	0.5
Copper sulphate	5	43	37	13.9	1.0
Ammonium sulphate	5	7	33	19.4	0.2
Ammonium sulphate	2	24	20	49.1	0.3
Sulphur flour	8	50	35	7.4	1.3
Soil sulphur	8	38	39	3.7	1.7
(Copper sulphate Iron sulphate Ammonium sulphate)	2 2 2	28	29	16.6	0.5
(Copper sulphate Iron sulphate Soil sulphur)	5 5 5	47	45	11.1	0.2
(Sulphur flour Ammonium sulphate)	8 2	17	43	14.8	1.0
Check, no treatment	-------------	47	37	8.9	0.6

experiments with cotton were started in 1938 to determine what effect such material would have when applied as a soil fungicide. Accordingly, oil was applied in the furrow at the rates of 2-, 4-, 8-, and 15-thousand gallons per acre in plots three rows wide and twenty feet long. These applications were made in November 1937, and the soil immediately re-bedded, so that the oil was directly beneath the planting bed. The experiment was laid out in a 5x5 latin square design. A two-row sorghum barrier separated the plots lengthwise and a seven-foot alley separated the ends of plots. Cotton was planted on these plots in the first week of April in 1938, and at approximately the same time in succeeding years. Results from this experiment are given in Table 13. Although the seed germinated and emerged fairly well in all plots, regardless of treatment, the plants became red and stunted as soon as the tap root penetrated the region of the oil. This condition was intensified at the higher rates of application. None of the plants grew enough in the 15,000 gallons per acre plots in 1938 to produce any cotton. In fact, very poor plants were obtained at all of the higher rates of application, and even those growing on the 2,000 gallons per acre plots were yellow and only about 2/3 the size of the plants on the check plots. This same effect was noticeable to

a lesser extent in 1939 and 1940 on those plots that had received the heaviest applications. In 1941, there seemed to be a stimulus from the residue where oil was applied at 15,000 and 8,000 gallons per acre. The yield of seed cotton on the 15,000 gallons per acre plots was approximately 50 percent greater than that on the plots receiving no treatment. The toxic residual effect on cotton from these higher rates of application had apparently been eliminated. There was still very little root rot in these plots in 1941. As a matter of fact, root rot was not present to any great extent in any of the plots in 1941, regardless of treatment. All treatments gave some control each year. No plants were killed by root rot on the 15,000 gallons per acre plots during the first three years of the test.

Due to the fact that there was some deleterious effects of oil on seedlings and an inhibition of plant growth later in the season in the crude oil experiment begun in 1938, and since there seemed to be effective control of root rot, an experiment of somewhat similar nature was repeated in another area except that the rate of application was changed and the oil was applied at different depths in the soil. In this experiment, oil was applied behind a subsoil plow reaching a depth of 18 inches and following a horse-drawn chisel subsoiler reaching an approximate depth of

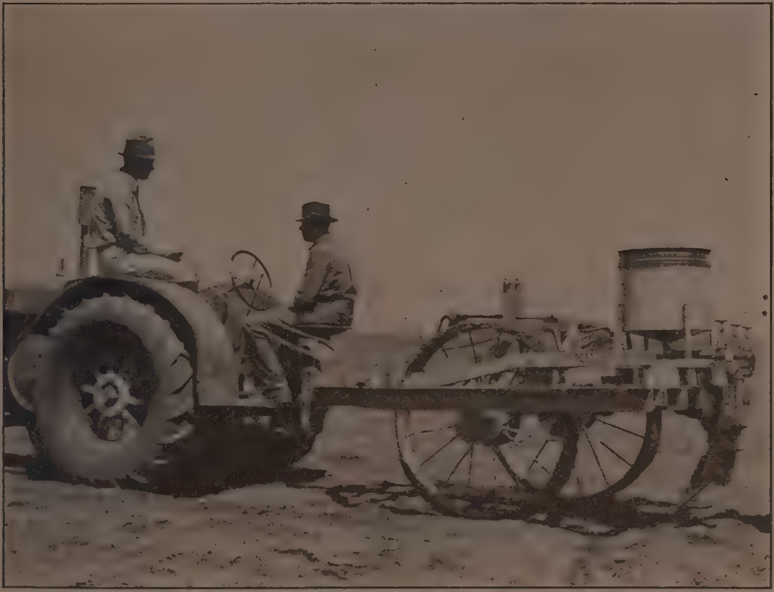

Figure 10. Subsoil plow and attachment for injecting fungicide solutions into the soil. The injector pipes deliver the solution at two different depths at definite rates.

Table 13. Effect of Crude Oil on Cotton Root Rot

Time and Depth of Application	Rate Gallons per Acre	Number of Plants Emerged per Row			Percent Root Rot					Yield of Seed Cotton Pounds per Acre				
		1938	1939	1940	1938	1939	1940	1941	Av.	1938	1939	1940	1941	Av.
Applied Nov., 1937 Furrow	2000	85	--------	51	12.9	7.1	3.5	8.0	7.9	298	348	363	486	374
	4000	75	--------	59	3.2	2.0	1.5	6.0	3.2	87	378	385	494	336
	8000	62	--------	57	6.7	0	0.7	2.0	2.4	7	305	378	588	320
	15000	51	--------	52	0	0	0	4.0	1.0	0	145	334	799	320
	none	97	--------	62	48.2	51.2	27.1	14.0	35.1	559	436	428	552	494
Applied Feb., 1939 18 inches	1000	--------	61	87	--------	2.8	19.9	52.5	25.1	--------	680	603	595	625
	2000	--------	60	100	--------	13.2	28.1	42.5	27.9	--------	586	641	598	608
	4000	--------	54	89	--------	7.2	23.7	52.5	27.8	--------	617	610	610	612
	8000	--------	40	92	--------	12.3	12.8	13.3	12.8	--------	508	600	503	537
	none	--------	83	87	--------	29.4	51.2	74.2	51.6	--------	578	424	518	507
12 inches	1000	--------	59	99	--------	15.1	35.4	77.1	42.5	--------	489	523	530	514
	2000	--------	43	84	--------	24.1	50.2	68.8	47.7	--------	554	341	537	477
	4000	--------	30	96	--------	32.0	21.2	37.1	30.1	--------	448	632	615	565
	8000	--------	16	78	--------	31.6	14.9	13.3	19.9	--------	341	513	518	457
	none	--------	79	92	--------	49.7	69.6	82.9	67.4	--------	445	295	353	364
Furrow	1000	--------	58	90	--------	8.4	28.0	54.2	30.2	--------	675	714	557	639
	2000	--------	36	78	--------	15.9	32.4	36.2	28.2	--------	639	557	670	622
	4000	--------	24	82	--------	31.5	16.6	40.0	29.4	--------	528	663	549	580
	8000	--------	8	86	--------	46.2	9.7	16.6	24.2	--------	276	544	484	435
	none	--------	80	105	--------	45.0	36.4	71.3	50.9	--------	547	639	552	579

12 inches. Applications were also made in the furrow similar to the experiment started in 1938. These treatments were made in February 1939 and cotton planted during the first week of April, and at the same time in 1940 and 1941. The furrow treatment was slightly different from the test begun in 1938, in that the furrow was opened about 3 inches deeper with a turn plow following the bedding plow. Immediately after the treatments, the land was rebedded so that the oil was directly beneath the planting bed. As shown in the second part of Table 13, all treatments were effective throughout the three-year period of the experiment in reducing root-rot losses of plants. There apparently was some toxic effect on cotton the first year from the highest rate of application, but this effect was not nearly as great as that obtained in the first experiment where the oil was applied at the same rate directly in the furrow with no deep tillage. Where the oil was applied at a depth of 18 inches, emergence was increased and root rot decreased. The high root-rot percentages for the higher rates of application in the furrow and at a 12-inch depth in 1939 are due to the fact that these figures were derived from plant counts and there were comparatively few plants to begin with. Actually, there were very few plants killed. In almost every case, yields were increased where all oil applications were made at a depth of 12 or 18 inches as compared with plots on which no oil was applied. Although the oil still exerted some toxic effect toward the root-rot fungus in 1941, there was no apparent effect upon the cotton plant.

Additional experiments were begun in 1940 in which oil at 250 and 500 gallons per acre and copper sulphate at 100 and 500 pounds per acre were applied with injecting equipment (Fig. 10) attached to a Killefer subsoil plow reaching a depth of approximately 18 inches. Planting was delayed in 1940 due to insufficient rain to settle the ground following land bedding, and it was delayed in 1941 because of continued wet weather. Little or no root rot occurred on any of the plots in either of these years. One of the main purposes in these experiments was to determine whether oil might be applied at comparatively low rates each year, or at longer intervals, so that there would be a non-toxic or possibly stimulating effect on cotton and yet reduce the loss from root rot.

SUMMARY

This bulletin gives the results of some cotton root-rot studies at the Blackland Experiment Station from 1931 to 1942.

Sclerotia of the cotton root-rot fungus, *Phymatotrichum omnivorum* (Shear) Duggar, were found in large quantities to depths of eight feet in cultivated lands and uncultivated prairies of the Central Texas Blacklands. Tests thus far indicate that these sclerotia may remain in a highly viable state, capable of reinfecting roots of susceptible plants, for at least twelve years.

Microscopical examinations of viable and non-viable sclerotia show some structural differences, the viable sclerotia having a relatively thin epidermis of thick-walled cells and a dense cytoplasm in the homogeneous

cells comprising the interior of the sclerotia, whereas the non-viable sclerotia have a thicker layer of epidermal cells and a less dense cytoplasm in the internal cells.

Two monocotyledonous plants day lilly *(Hemerocallis* sp.) and Tradescantia, parasitized by the root-rot fungus showed typical penetration and destruction of root tissues by mycelium of *P. Omnivorum.*

Sesbania, guar, sweet clovers and certain varieties of cowpeas have been found adaptable to Blackland conditions and have shown, with the exception of sweet clovers, a comparatively high resistance to the cotton root-rot disease. Sesbania and guar are regarded as highly resistant legumes. Sesbania and cowpeas have been used effectively as summer catch-crops on oat stubble for green-manuring purposes.

Rotations in which legumes or non-legumes are incorporated as green-manure crops have proven effective in reducing root rot and increasing crop yields, even though the rotation, in some cases, was of short duration. In one experiment in 1941, outstanding control of root rot was obtained by plowing under hubam residue that remained after the crop was harvested for hay or seed.

Subsoiling at a depth of from 15 to 30 inches has given consistent reductions in root rot, but has not increased yields sufficiently to pay for the costs of the operation.

Cotton plants killed early in the season produced little or no crop, whereas those that succumbed to root rot in the latter part of the growing season produced an excellent crop of cotton. Seed from plants killed at a relatively early stage were found to be of a comparatively poor quality, having a low oil and protein content and germinating at a very low rate.

Experiments over a three-year period have shown that a low rate of seeding for cotton resulted in a small percentage of root-rot infection and a comparatively high cotton yield. As the rate of planting was increased beyond that required for a normal stand, the incidence of root rot was increased and cotton yields likewise were found to decrease.

Plowing under of the cotton stalks immediately after picking, while they were still in a green condition, reduced root rot and increased cotton yields. Supplementing this treatment with 120 pounds per acre of nitrogen provided no extra benefit.

Crude oil applied at various depths in field plots of cotton at rates of from 1,000 to 15,000 gallons per acre effectively controlled root rot, and, after the toxic effects of the treatments had disappeared, resulted in an apparent increase in cotton yield. A combination of two ounces each of copper sulphate, iron suphate and soil sulphur per cubic foot of soil was the most effective of a number of treatments used in controlling root rot and chlorosis of roses.

LITERATURE CITED

1. Bach, W. J., 1931. Effect of Bluestone Solution on Root Rot of Citrus. Texas Agr. Exp. Sta. Ann. Rpt. 44:68.
2. Blank, L. M., 1941. Responses of Phymatotrichum Omnivorum to Certain Trace Elements. Jour. Agr. Res. 62:129-159.
3. Chamberlain, C. J., 1932. Methods in Plant Histology. Univ. of Chicago Press, Chicago.
4. Dunlap, A. A., 1941. A convenient Soil-Culture Method for Obtaining Sclerotia of the Cotton Root Rot Fungus. Am. Jour. Bot. 28:945-947.
5. Ezekiel, W. N., 1939. Longevity of Sclerotia. Texas Agr. Exp. Sta. Ann. Rpt. 52:84-85.
6. Harvey, R. B. Laboratory Outline of Plant Microchemistry. Univ. of Minnesota, unpublished.
7. Hooton, D. R., 1940. Influence of Deep Tillage on Cotton Root Rot Infection. (Abs.) Proc. 5th Ann. Meeting Cotton Disease Council. Mimeographed.
8. Johansen, D. A., 1940. Plant Microtechnique. McGraw-Hill Book Co., Inc., New York.
9. King, C. J., and Loomis, H. F., 1926. Experiments on the Control of Cotton Root Rot in Arizona. Jour. Agr. Res. 32:297-310.
10. King, C. J., and Loomis, H. F., 1929. Further Studies of Cotton Root Rot in Arizona with a Description of a Sclerotium Stage of the Fungus. Jour. Agr. Res. 39:641-676.
11. King, C. J., and Hope, Claude, 1932. Distribution of the Cotton Root Rot Fungus in Soil and in Plant Tissues in Relation to Control by Disinfectants. Jour. Agr. Res. 45:725-740.
12. McNamara, Homer C., Wester, R. E., and Gunn, K. C., 1934. Persistent Strands of the Cotton Root Rot Fungus in Texas. Jour. Agr. Res. 49:531-538.
13. Neal, D. C., 1929. The Occurrence of Viable Cotton Root Rot Sclerotia in Nature. Science 70:409-410.
14. Neal, D. C., Wester, R. E., and Gunn, K. C., 1934. Morphology and Life History of the Cotton Root Rot Fungus in Texas. Jour. Agr. Res. 49:539-548.
15. Ratliffe, George T., 1929. A Prolonged Saprophytic Stage of the Cotton Root Rot Fungus. U. S. Dept. Agr. Cir. 67.
16. Ratliffe, Geo. T., 1934. Cotton Root Rot as Affected by Crop Rotation and Tillage at San Antonio, Tex. U. S. Dept. Agr. Tech. Bul. 436.
17. Rea, H. E., 1939. The Control of Cotton Root Rot in the Blackland Region of Texas. Texas Agr. Exp. Sta. Bul. 575.
18. Rogers, C. H., 1936. Apparatus and Procedure for Separating Cotton Root Rot Sclerotia from Soil Samples. Jour. Agr. Res. 52:73-79.
19. Rogers, C. H., 1936. Viability of Sclerotia. Texas Agr. Exp. Sta. Ann. Rpt. 49:204.
20. Rogers, C. H., 1936. Cotton Root Rot and Weeds in Native Hay Meadows of Central Texas. Jour. Am. Soc. Agron. 28:820-823.
21. Rogers, C. H., 1937. The Effect of Three-and Four-Year Rotations on Cotton Root Rot in the Central Texas Blacklands. Jour. Amer. Soc. Agron. 29:668-680.
22. Rogers, C. H., 1938. Growth of Phymatotrichum Omnivorum in Solutions with Varying Amounts of Certain Mineral Elements. Am. Jour. Bot. 25:621-624.
23. Rogers, C. H., 1939. The Relation of Moisture and Temperature to Growth of the Cotton Root Rot Fungus. Jour. Agr. Res. 58:701-709.
24. Rogers, C. H., 1940. Sclerotial Studies. Texas Agr. Exp. Sta. Ann. Rpt. 53:168
25. Streets, R. B., 1937. Phymatotrichum (Cotton or Texas) Root Rot in Arizona, Ariz. Agr. Exp. Sta. Tech. Bul. 71.
26. Taubenhaus, J. J., 1936. Laboratory Studies on Longevity of Sclerotia. Texas Agr. Exp. Sta. Ann. Rpt. 49:86.